California Public Works Studies Program

EVALUATION OF MARKED AND UNMARKED CROSSWALKS AT INTERSECTIONS IN CALIFORNIA

Final Report

by

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16. Abstract

For two decades transportation agencies in California have been reluctant to mark pedestrian crosswalks. Studies in California concluded that at unsignalized intersections, marked crosswalks have a higher frequency of accidents that unmarked crosswalks. Recent work supported by the FHWA called in question the California practice. The objective of this study was to examine numerous marked and unmarked crosswalks to compare the acident experiences. After a literature search, 380 intersections out of more than 10,000 on California state highways were selected at random. Five years of accident data and 1989 traffic volumes were obtained for all 380 intersections. Pedestrian counts were completed at 55 of the intersections.

The analysis utilized the Wilcoxon Rank Sum tests to assess whether or not there were differences in pedestrian-vehicle accident rates between intersections with and without markings. The major results were: 1) at unsignalized intersections marked crosswalks clearly featured higher pedestrian-vehicle accident rates than unmarked crosswalks; 2) for signalized intersections the results were inconclusive; 3) there is no compelling reason for Caltrans to change intersection crosswalk marking policy.

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In addition to the above there were nearly 40 college students from several California campuses who traveled to various sites in urban areas to perform counts at nearly 200 intersections.

DISCLAIMER

1.0 INTRODUCTION

1.1 BACKGROUND

For a number of years, there has been a general reluctance among California transportation agencies to use marked pedestrian crosswalks at unsignalized intersections. In previous years, marked crosswalks were assumed to prevent accidents, and were commonly placed at locations where pedestrians and vehicles faced potential conflict. However, since 1960, a number of studies relating pedestrian safety and marked crosswalks have been conducted in Southern California which have produced surprising, yet consistent results: at unsignalized locations, marked crosswalks account for more pedestrian accidents than similar, unmarked locations. This has resulted in an increased tendency to leave crossings unmarked unless special conditions would warrant their placement. Brief summaries of two selected studies follow.

The San Diego crosswalk study by Bruce Herms (1972) focused on pedestrian accident data collected over a five year period in the 1960's. Four hundred uncontrolled intersections were selected, with each location having one marked and one unmarked crosswalk crossing the major street. Accident data were analyzed, showing an accident ratio of 5.7 to 1 in marked vs. unmarked crosswalks. The study also showed pedestrian usage to be 2.9 to 1 in marked vs. unmarked crosswalks. With usage adjustments, it was determined that marked crosswalks accounted for twice as many pedestrian-related accidents as unmarked crosswalks.

The Herms study is the basis of current California Department of Transportation (Caltrans) policy. In California the crosswalk marking policy centers on the notion that markings should be used primarily to channel pedestrians and not as a safety feature. This is explained in the Traffic Manual 6-02.12 published by the State of California (1993).

Another study was conducted by Willdan Associates for the Department of Public Works of the City of Long Beach (1986) in an effort to respond to several requests for installation of crosswalks at uncontrolled locations. This study reinforced the earlier work from San Diego. Present practice at the time of the requests was not to install marked crosswalks, and this study was intended to determine whether its policies were still appropriate or should be changed. The project approach was to review accident reports spanning 10 years, from 1976 to 1985. Information obtained from the 3,490 accident reports was entered into a computer database which enabled the creation of summaries of accident types and location configurations. By using pedestrian counts obtained in the previously mentioned study, it was concluded that the Department of Public Works' policy should be retained. This policy reads: "Marked crosswalks shall not be installed at uncontrolled locations unless special study by the City Traffic Engineer determines such marking to be necessary and desirable for the specific purpose of encouraging concentration of pedestrians at a certain point".

In recent work reported in 1983 by Henry Tobey et. al. for the Federal Highway Administration (FHWA), findings were reported that did not concur with the two other studies. This study looked at crosswalks taking into consideration a number of factors, including whether marked or unmarked, functional classification, number of lanes, channelization, parking restrictions, pedestrian accommodations, street lighting, commercial lighting, adjoining land use, intersection type, lane configuration, and signalization. By using multivariable statistical analysis, a hazard score was determined for a certain characteristic, deeming it "less hazardous" or "more hazardous". The results of this study appear to favor marked crosswalks over current Caltrans practice. This has raised new questions as to the appropriateness of current policies concerning the marking of crosswalks.

1.2 NATURE OF THE PROBLEM TO BE ADDRESSED

Clearly there is conflicting information pertaining to the effect of crosswalk markings on pedestrian-related accident rates. While there is some argument as to the relative benefits of crosswalk markings, many who have looked at the question would concur that the presence of crosswalk markings does in some way have a positive effect on pedestrian-related accident rates. However, there are those who not only disagree but believe the opposite to be true. It is precisely this question of how such markings contribute to the overall safety at intersections on state highways that was the focus of this study.

1.3 OBJECTIVES OF THE STUDY

This study endeavors to address the question of whether crosswalk markings contribute to or mitigate higher pedestrian-related accident rates. Specifically, the project looked at the pedestrian safety effects of crosswalk markings on state highway approaches and intersections as a whole. Another objective of the study was to determine the appropriateness of having marked or unmarked crosswalks at unsignalized as well as signalized locations on state highways. Finally, this information can be helpful in determining whether or not Caltrans should consider changing its crosswalk marking policy.

1.4 SCOPE OF THE RESEARCH

The literature review contained herein reported the findings of relevant research published during the previous thirty years. It is comprehensive in nature and serves as the informational foundation for the research which followed. Both state and national studies were surveyed concerning crosswalk placement. The existing research helped to prepare and familiarize the project research team with crosswalk treatments policies employed in various jurisdictions of the United States.

The intersection selection process employed in this research was designed to result in a representative, randomly selected population of intersections for use during the analysis phase of the project. Comprehensive review of state highway records was undertaken to achieve this. Intersections which were not shown to be stable during the five year period covered by the study were eliminated, as were others that did not meet requirements established above.

The pedestrian volume field counts were conducted at various sites in eight Caltrans districts throughout the state of California. The assistance and direction of Caltrans district traffic engineering personnel was utilized in many parts of the state to develop reliable pedestrian volume counts. These volumes were then used, together with accident and vehicular data, to calculate accident rates based on pedestrian usage during the analysis phase of the project.

The accident data was collected via on-site visits to Caltrans district offices in 1993, where an intensive review of accident reports was conducted. The Traffic Accident Surveillance and Analysis System (TASAS) computer database maintained by Caltrans was also used during the accident data collection phase of the project.

The analysis of the data was performed using statistical analysis software and modeling procedures. A large database was developed containing state highway intersection and approach characteristics. The information contained in the database was then employed in the analysis and comparison of pedestrian-related accident rates between marked and unmarked crosswalks. Levels of significance were determined to separate causal relationships from random occurrence.

The results were tabulated and are found in Chapter 5, as well as in the "Findings and Conclusions" section of this report (Chapter 6).

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is one portion of the study **Evaluation of Marked and Unmarked Crosswalks at Intersections in California** sponsored by Caltrans. The purpose of this literature review is to examine previous work done, in part or in whole, on the safety of marked and/or unmarked crosswalks. While the main body of this study is to analyze intersections only within California, the literature review is more expansive and covers studies within California, other parts of the United States, and includes some foreign references.

The purposes of crosswalk markings are outlined in the Manual on Uniform Traffic Control Devices (MUTCD) Section 3B-18:

> "Crosswalk markings at signalized intersections and across intersection approaches on which traffic stops, serve primarily to guide pedestrians in the proper paths. Crosswalk markings across roadways on which traffic is not controlled by traffic signals or STOP signs, must also serve to warn the motorist of a pedestrian crossing point. At non-intersection locations, these markings legally establish the crosswalk."

However, the MUTCD (Section 3B-18) provides only general guidelines regarding the application of crosswalk markings:

> "Crosswalks should be marked at all intersections where there is substantial conflict between vehicle and pedestrian movements. Marked crosswalks should also be provided at other appropriate points of pedestrian concentration, such as at loading islands, midblock pedestrian crossings, or where pedestrians could not otherwise recognize the proper place to cross."

The lack of specific guidelines for the placement of marked crosswalks has led some cities and states to develop their own guidelines or warrants for their placement. **However, marking of crosswalks is often done in response to citizen complaints or political pressure. This frequently causes marked crosswalks to be misused. The public tends to place a great amount of confidence in the marked crosswalk as a safety device.** This confidence in the marked crosswalk as a safety device is at the center of an increasing controversy over the actual effectiveness of marked crosswalks.

Although some still hold to the idea that marked crosswalks are a benefit to the general public, there has been growing concern that marked crosswalks may be more of a detriment than a benefit. This disagreement has caused Caltrans to reevaluate their current policies concerning the installation of marked crosswalks. The purpose of this project is to assess the appropriateness of having marked or unmarked crosswalks on state highways.

The discussion that follows will review some of the features that many people feel can improve pedestrian safety with regard to marked crosswalks. Also, a number of case studies are reviewed showing previous work done to determine whether marked crosswalks are safe or less safe, and what characteristics make marked crosswalks safe or unsafe. The policies of a few Southern California agencies are reviewed so that the reader will have some idea of current policies regarding marked crosswalks in that state. The guidelines or warrants that some engineers are using for the placement of marked crosswalks are also included in this discussion as well as some perceived advantages and disadvantages of marked crosswalks. Appendices are included listing detailed information regarding the guidelines or warrants currently in use for marked crosswalks.

2.2 PRESENT CALTRANS POLICY

The present Caltrans policy as stated in the Traffic Manual 6-02.12 of the State of California (1993) discourages the marking of crosswalks unless said marking is intended primarily to channelize pedestrians. This policy is based on the notion that while a marked crosswalk is readily apparent to the pedestrian, it is less so to motorists traveling at typical approach speeds at intersections. This situation is believed to instill a false sense of security in the pedestrian, which may result in pedestrian/vehicle conflicts. Caltrans therefore advocates the use of the marked crosswalk as a channelization device rather than as a safety device.

2.3 RIGHT OF WAY

Willdan Associates (1986), in their crosswalk pedestrian safety study report for the City of Long Beach, quoted section 21950 of the California Vehicle Code, which states:

> "The driver of a vehicle shall yield the right-of-way to a pedestrian crossing the roadway within any marked crosswalk or within any unmarked crosswalk at an intersection. . . . The provisions of this section shall not relieve a pedestrian from the duty of using due care for his safety. No pedestrian shall suddenly leave a curb or other place of safety and walk or

> run into the path of a vehicle which is so close as to constitute an immediate hazard . . . ."

This statute clearly identifies the responsibility of both the pedestrian and the motorist. Both shall approach the crosswalk with caution. However, some pedestrians seem to view this statute as if they have the right-of-way at any marked crosswalk regardless of the situation and that the vehicle operator is solely responsible for safety at the crosswalk. If a pedestrian in a marked crosswalk steps into the path of an approaching vehicle causing the driver of the vehicle to slam on its brakes to avoid a collision, the pedestrian is in violation of this statute as much as is a driver refusing to give the right-of-way to a pedestrian already in the crosswalk. This right-of-way and responsibility controversy is at the center of the debate over the effectiveness of marked crosswalks.

If the pedestrian uses the marked crosswalk in the appropriate manner as described in the statute, the pedestrian does have the right-of-way. State laws generally follow the Uniform Vehicle Code (UVC) guidelines which give the right-of-way in marked and unmarked crosswalks to pedestrians. These laws have been enacted to protect the pedestrian; however, they may not always be enforced.

Another issue raised is that of the driver-pedestrian obligation to yield the right-of-way at crosswalks, which often is eventually resolved in civil suits. Herms (1972) suggested that a disadvantage of marked crosswalks is that they may cause an increase in insurance costs. Because of the cost of litigation, resolving these conflicts in court could, in all likelihood, increase community-wide accident insurance rates.

According to Todd (1987), "No statistical analysis is needed to prove that safety is jeopardized . . . when a driver and a pedestrian are on a collision course and one of the two is encouraged by the law to assume he may rely on the other to avoid the accident. The courts have struggled in vain to resolve the contradictions between statutory right-of-way rules and common law responsibilities, which require everybody to exercise reasonable care at all times. Said a Utah judge:

> 'This case is fraught with considerable difficulty, arising out of conflicting principles of law. The first is the familiar principle that one must exercise reasonable care for his own safety. The other is that a person having a right-of-way . . . ought to be protected in the exercise of that right, and is not bound to anticipate an unlawful or negligent act on the part of another.'"

The point is made by Todd that if pedestrians were foolhardy enough to exercise their legal right, they could be killed.

The lack of sufficient enforcement by public officials to protect the right-of-way of pedestrians is considered a major flaw in pedestrian safety. Haight and Olsen (1981) conducted a survey of state enforcement practices of pedestrian safety laws They reported, that ". . . with few exceptions, most notably California, enforcement of pedestrian safety laws. . . receives little emphasis and is regarded as politically difficult. Except in California, and perhaps in Ohio, officials seem to be saying that enforcement would be extremely unpopular and not worth the effort." They stated that Pennsylvania was ranked next to last in degree of conformity with the revised Uniform Vehicle Code. Because of the possibility of losing up to $30 million in federal aid, Pennsylvania updated their code. Included in the updated code was legislation giving total right-of-way to pedestrians at crosswalks. However, when informed about the legislation, law enforcement officials refused to enforce the new law. They claimed that it was a bad law and was only enacted to gain access to federal funds. The researchers conclude their article by saying that laws that have been enacted to protect the pedestrian need to be enforced.

Some lack of enforcement may be due to limited law enforcement resources. However, very little study has been done to determine whether increased enforcement will decrease motorist violations and reduce accidents crosswalks. More studies would need to be done to substantiate any claims about increased enforcement and its effects.

2.4 EDUCATION

Herms' (1972) evaluation of the crosswalk study done in San Diego determined that the highest incidence of pedestrian accidents involves the very young and the very old in both marked and unmarked crosswalks. Robbins (1969), Senior Traffic Engineer for the City of San Diego, suggested that what may be needed is a program to educate pedestrians to use the same precautions on marked crosswalks that they employ on unmarked crosswalks. Others have also pointed out this need for education, especially for the young who tend to be a high risk group for auto-pedestrian accidents.

2.4.1 SALT LAKE CITY, UT

Reading (1973) performed an experiment to determine what effect teaching the proper use of marked crosswalks would have on the behavior of children. His project, done in Salt Lake City, involved elementary school children. The first day of the project, the children leaving the school between 9:45 a.m. and 10:10 a.m. participated in a 20 to 30 minute assembly before leaving the school. The assembly program included a short lecture by a project coordinator, a brief question/answer period, a demonstration of appropriate street crossing behaviors, and a role-playing period during which several students were chosen from the audience to demonstrate correct street crossing behavior as presented during the program. After the assembly, the children who crossed the street in the manner demonstrated during the assembly were given a piece of candy, "a good pedestrian citation", and told that he or she had done a good job crossing the street. This was done to positively reinforce the action of the child. Two days later this same routine was performed for another group of children leaving the school between 10:45 a.m. and 11:10 a.m. as well as being continued for the children leaving at the earlier time. Three days later this same procedure was again followed for the last group of children leaving the school between 11:45 a.m. and 12:10 p.m. as well as for the two other groups of children leaving at the earlier times. This routine was continued until the end of the project.

During this project ". . . appropriate street crossing behavior was defined in the following manner: the pedestrian approaching an intersection on foot was to break stride and come to a complete stop at the curb of the intersection, make discrete observing responses in all directions of potential traffic flow for a period of at least three seconds, then proceed across the street within the confines of the pedestrian crosswalk. The selection of these requirements for a safe crossing was by no means arbitrary. **Statistics from Salt Lake City's accident reports showed that 85% of all auto-pedestrian accidents were caused or contributed to by the pedestrian's inattentiveness."** (Reading, p. 19, emphasis added).

Table 2.1 gives the percentage of students showing compliance with safe street crossing behavior during the initial three days of the study. As can be seen, the baseline levels of compliance are between 4% and 12% (no baseline was available for the first group). With each successive day one new group was exposed to the assembly. As Table 2.1 shows, after each assembly the percentage of compliance for the respective group increased between 53% and 57%. For the last two groups this represented a 4 to 14 fold increase in the number of children showing safe street crossing behavior.

Table 2.1. Percentages of Students Exhibiting Safe Street Crossing Behavior During the First Three Days of the Study.

Group/Period	Day				
	1	Δ	2	Δ	3
9:45-10:10	63%-	-	-	-	-
10:45-11:10	12%	53%	65%	-	-
11:45-12:10	4%	0%	4%	57%	61%

Δ = Difference from one day to the next.

Reading (1973) suggested that one conclusion that could be reached from this study is that the majority of auto-pedestrian accidents are the fault of the pedestrian. He also suggested that behavior modification, through education when directed by traffic engineering expertise, can be effective in increasing safe street crossing behavior. He went on to say that past research indicates instruction given without providing reinforcement for the behavior has a short-lived effect, if indeed it has any effect. Providing reinforcement for unspecified responses also may have a less than desirable effect. The best procedure, apparently is providing reinforcement for specified responses.

2.4.2 HALIFAX, N.S.

Kennedy (1984) evaluated a study that took place in Halifax, a city in the province of Nova Scotia. This study was done to determine the effect of education on improving pedestrian safety. A safety program was begun in 1974. "This program included the use of 'zebra' crosswalks, which are special crosswalks installed only where necessary to guide and control pedestrians in specific corridors. . . . The difference between the 'zebra' and regular crosswalks in Halifax is the use of extra markings and devices: angled pavement markings; side-mounted signs; overhead crosswalk signs; large 'X's' painted on the roadway surface 15 to 30 meters (50 to 100 feet) [in advance of approaches].

"Safety education involved the distribution of pedestrian safety coloring books and corresponding lessons to be taught as part of the school curriculum. These materials were distributed annually in the Spring of each year and were supplemented by safety presentations given by a traffic analyst, using a short film and a question/answer session with the students. . . . The pedestrian safety coloring book and cartoons left an impact and produced results beyond the school grounds. . . . Also, public information and education were done through local media advertising at selected times of the year.

". . . The yearly high of 256 pedestrian accidents in 1973 and the 7-year average of 218 per year provided the incentive for creating the program. The figures show[ed] a dramatic decrease in accidents since 1974; that is, a 44% decrease to 112 in 1981 and . . . a similar 50% reduction in reported pedestrian accidents for the 5-9 year old age group from 38 in 1974 to 19 in 1981." (Kennedy, pp. 35-36) The statistics showed a decrease in pedestrian accidents every year but one since the implementation of the program in 1974. The reported pedestrian accident total for 1982 at the time of Kennedy's report indicated a trend similar to that of 1981. The author never states whether or not these decreases were statistically significant.

"Halifax's safety record at 'zebra' crosswalks is relatively good considering the number of crossings at marked crosswalks per year. In Halifax, there are 200 zebra crosswalks (uncontrolled crosswalks), 200 school days (maximum pedestrian traffic), and 300 crossings per day on the average per crosswalk. It follows that there are approximately 12,000,000 crossings at zebra crosswalks in a year. Therefore, in three years the ratio of accidents to crossings is 39 to 36,000,000, approximately 1 accident per 1 million crossing[s]." (Kennedy, p. 36)

However, from the study structure, it is not clear if the improved accident rate is the result of the education program, the zebra crosswalks and markings, or the interaction of both.

2.4.3 GENERAL APPLICATION

Ranck (1989) stated that there have been other major cities that have incorporated traffic safety educational programs which have led to significant reductions in auto-pedestrian collisions, especially for children. Educating the public, especially children, is a promising countermeasure for decreasing auto-pedestrian accidents. The studies that have been done all seem to have had positive results. However, this countermeasure is far from being fully utilized. According to Ranck, "Although specific traffic safety programs, such as mandatory usage of safety belts, tougher drinking-and-driving measures, enhanced roadway delineation, and elimination of roadside hazards, . . . [have reduced] traffic injuries and fatalities overall, the numbers of pedestrian/traffic collisions, injuries and deaths have remained largely unchanged." He claims much can be done to change this by implementing educational programs aimed directly at increasing pedestrian safety.

2.5 PEDESTRIAN ATTITUDES

Kennedy (1984) in his evaluation of the Halifax safety program suggested that, in addition to improving the traffic engineering aspects of delineation by zebra crosswalks, the attitude adjustment of the pedestrian is critical.

The belief that the marked crosswalk is a safety device is a major flaw in the attitude of the pedestrian. Todd (1987) quoted a study on signalized intersections in Portland, Oregon. The study determined that only 29 percent of pedestrians looked for vehicles before they stepped onto the road with the signal in their favor. This apparent false sense of security leads to reduced pedestrian alertness and thus acts as a detriment to safety since the presence of two painted stripes cannot be expected to stop the movement of an approaching vehicle. Despite this fact, Willdan Associates (1986) surmised that a great number of pedestrians seem to view a marked crosswalk as their license to cross with complete disregard for oncoming vehicular traffic. The results of such actions by the pedestrian only increase the likelihood that the motorist will have to take drastic action to avoid a collision.

Burritt (1990) determined that the view the pedestrian has of the crosswalk leads to other flaws in the attitude of the pedestrian. The marked crosswalk appears to the pedestrian as an impressive sight. The pedestrian also tends to assume that the motorist has the same view of the crosswalk. However, the view the motorist has of the crosswalk can be "... affected by road alignment, irregularities in the pavement, and other variables like weather, dirty windshields, glare, and adverse lighting conditions." The pedestrian assumes a false sense-of-security if he thinks the motorist has the same view of the crosswalk as he does. This false sense-of-security leads to an aggressive attitude in using the crosswalk. This aggressive attitude can be responsible for placing the pedestrian in a dangerous situation. Aggressiveness and over-confidence are flaws in the attitude of the pedestrian that can lead to a greater number of accidents in marked crosswalks than in unmarked crosswalks.

2.6 CASE STUDIES

Various studies have been done in which the safety aspects of marked or unmarked crosswalks have been evaluated. Some of these studies involve before and after analysis, either looking at the effects of crosswalk removal or the effects of marking a new crosswalk. Two ways to evaluate the effect of marked or unmarked crosswalks **is by measuring either the effect on accidents or the effect on behavior which could result in an accident.** Both types of studies are reviewed here. Although some of the cited studies covered many factors which may affect pedestrian safety, the results dealing primarily with marked and unmarked crosswalks will be stressed.

2.6.1 BEHAVIOR STUDIES

Several studies of motorist and pedestrian behavior with respect to marked crosswalks have been completed. While most studies deal with the effect of the presence or absence of marked crosswalks, at least one presented here focuses on the effects of the type of crosswalk used.

Hauck and Bates (1976) performed a study in Peoria, Illinois, on crosswalks before and after they were re-marked. "The operational effectiveness of well-marked crosswalks was determined by comparing pedestrian and motorist observance of worn crosswalks with observance after these crosswalks were re-marked. For purposes of this study, worn crosswalks were considered to be marked crosswalks with at least part of the markings worn away by traffic. . . . The effectiveness of well-marked crosswalks was evaluated by collecting and comparing pedestrian and motorist violation data at 17 crosswalk locations in Peoria, both before and after . . . re-mark[ing]. . . . Data at individual crosswalk locations were too variable to form significant conclusions.

"However, analysis of the data on an overall basis showed a reduction in the percentage of violations at most locations [after re-marking of the crosswalk]. Also, when data from all locations were combined for each of the six violation types, it was found that the ratio of violations to violations plus non-violations decreased significantly after crosswalks were re-marked. It can be concluded that there was a significant increase in pedestrian and motorist observance of correct crosswalk usage at [these] 17 combined locations in the Peoria area after [crosswalk] re-marking. . . ." (Hauck and Bates, pp. 27-28)

Knoblauch, Tustin, Smith, and Pietrucha (1988) reviewed three case studies in their report on marked crosswalks. The first case study occurred at ". . . Belleview Boulevard which is a major east-west collector passing through residential and commercial areas in southern Fairfax County, Virginia. The segment of interest was a section approximately 1/2 mile long connecting the George Washington Parkway with Fort Hunt Road, both of which are major north-south arterials." There are four intersections on this stretch of roadway and only one intersection at the time of the study had a marked crosswalk. A " . . . marking project called for two new crosswalks to be installed and the one existing crosswalk to remain in place . . . . The purpose of [the study] was to determine the effect of crosswalk markings on driver and pedestrian behavior." Data were collected to determine 1) vehicle speed with no pedestrian present, 2) vehicle speed with a pedestrian on the roadway, 3) vehicle speed with a pedestrian on the roadside, 4) pedestrian crossing locations and 5) pedestrian looking behavior. "Data were collected for a total of 20 hours before the crosswalks were installed and for a similar period several months after they were installed. The after data were collected several months after the crosswalks were installed because the project was not concerned with short-term or acclimation effects." The results of the study suggest that very little change occurred in either the mean vehicular travel speed or in the behavior of both motorists and pedestrians between the before and after conditions at all four locations.

The second case study reviewed by Knoblauch et al. (1988) took place at ". . . Eisenhower Avenue [which] is a two-way, four-lane divided arterial in Alexandria, Virginia. [This street was] built to access the Washington Metropolitan Area Transit Metro subway station . . . and provide needed capacity for peak-hour kiss-and-ride [traffic]. One major office building in the area benefits from the location of the road, but the majority of the traffic is in the morning and evening peaks." A before and after analysis was done to determine the effect a marked crosswalk would have on pedestrian and motorist behavior. "Observations [of the pedestrians at the crosswalk area] included an estimate of age, sex, looking behavior (whether there was head movement), length of time in the roadway, direction of travel, time of day, and location of the pedestrian in or out of the crosswalk area." Motorists observations included vehicle speed, type of vehicle, direction of travel, and pedestrian activity within the driver's observation zone. The results of the study indicated no change in vehicle approach speeds before or after the crosswalk was installed. There was some evidence from the results that after the marked crosswalk was in place the number of people crossing within the crosswalk increased. Without the marked crosswalk some pedestrians crossed the street somewhat diagonally. Consequently, marked crosswalks reduced the distance they were exposed to traffic. The results also suggested some pedestrians became less cautious. All of the pedestrians looked before entering the roadway both before and after the crosswalk was marked. However, significantly fewer pedestrians looked during the first half of the crossing after the crosswalk was marked than before.

In the third case reviewed by Knoblauch et al. (1988) the behavior of motorists and pedestrians using two different types of crosswalk was analyzed. The study involved Fort Lincoln Drive, a major collector street in the planned community of Fort Lincoln, an area of urban redevelopment in Washington D.C. Most of Fort Lincoln Drive "is a four-lane divided road, however, when it passes the local grammar school it narrows to a two-lane undivided section. . . . [Located] in this two-lane section . . . is a midblock crosswalk linking the school with nearby housing areas. In an effort to add more visibility to this midblock . . . crossing, the [local] . . . government decided to change the crosswalk configuration. The initial pattern was two parallel lines spaced eight feet apart. The new pattern is a [cross]hatched diagonal configuration. This change in the crosswalk configuration presented an interesting opportunity to see if different crosswalk patterns affected driver or pedestrian behavior. Data were collected on vehicle speeds . . . and pedestrian crossing and looking behavior. The results [of the study] showed little difference in the mean vehicle speeds between the two different marking types. . . . The type of crossing had no significant effect on motorist behavior."

The pedestrian behavior, however, was affected by the different marking types. When the parallel lines were in place, 47.2 percent of the pedestrians crossed entirely in the crosswalk. After the diagonal configuration was installed, this increased to 59.2 percent. Since the number of pedestrians who crossed partially in the crosswalk (late entry or early departure) decreased from 9.0 percent to 3.3 percent, it appears that the diagonal crosswalk is somewhat more effective in attracting pedestrians and at retaining them during the entire crossing. "There was also a change in the looking behavior [of the pedestrian] between the parallel line marking and the diagonal marking. The majority of the shift took place [from] the 'did not look' category [to] the 'looked prior to and during' category. The . . . [results] show that 39.5 percent of the pedestrians observed did not look when the parallel line marking was in place and only 4.7 percent looked prior to and during crossing. [After] the diagonal marking was installed, only 9.2 percent of the pedestrians did not look (as opposed to 39.5% before), while the number of pedestrians who looked prior to and during crossing rose to 41.7 percent. At the Fort Lincoln . . . site, the diagonal configuration was found to be somewhat more effective than the parallel lines at inducing pedestrians to use the crosswalk and also resulted in an increase in the number of pedestrians who looked for oncoming traffic prior to and during crossing." (Knoblauch et al., pp. 27-29)

In all of the behavior studies looked at, consistencies were found for motorists, and to some extent, pedestrians. Whether the crosswalk was re-marked, newly installed, or changed with respect to type (parallel to diagonal crosshatched), vehicular speeds were not found to be significantly affected.

For pedestrians, re-marked crosswalks and newly installed crosswalks both served to improve channelization during crossing. Some evidence indicated that newly installed crosswalks resulted in a slight reduction of pedestrians continuing to look for vehicular traffic during the first one-half of the crossing trip. In the one case examined where crosswalk type was changed from two parallel lines to diagonal crosshatching the effect on pedestrian behavior was an increase in both channelization and in looking prior to and during crossing.

2.6.2 ACCIDENT STUDIES

Herms (1972) reviewed the results of a five year study in San Diego, California involving 400 unsignalized intersections. Only intersections that had one painted crosswalk and one unpainted crosswalk, both crossing the major flow of traffic were used. Before the actual study began, a 24-hour manual pedestrian count was done at 40 of the intersections. These counts were performed to obtain a sample of the number of pedestrians using marked crosswalks versus unmarked crosswalks. From these counts it was discovered that the ratio of pedestrians using the marked crosswalk versus the number of pedestrians using the unmarked crosswalk was 2.86 to 1.00. The total number of fatal pedestrian accidents occurring in the 400 intersections during the 5-year period was 18 in the marked crosswalks and 3 in the unmarked crosswalks, a ratio of 6 to 1. During this same period, the total pedestrian accidents (fatal and non-fatal) occurring was 177 in marked and 31 in unmarked crosswalks, representing a ratio of 5.7 to 1.0. As might be expected, the highest incidence of pedestrian accidents involved the very young and the very old in both the marked and unmarked crosswalks. The article concludes that the poor accident record is probably not due to the crosswalk being marked, as much as it is a reflection on the pedestrians' attitude and behavior when using the marked crosswalk.

Tobey, Shunamen, and Knoblauch (1983) conducted a study of factors contributing to pedestrian hazard in five regions of the United States. Their far-reaching study, focused on urban locations, included analysis of crosswalks and the amount of intersection control on pedestrian hazard or risk. To determine risk they first surveyed the behavior of pedestrians at 762 intersections. At these sites they also measured the type, control, and other physical features of the intersections. They then randomly sampled pedestrian-vehicular accident records at 495 intersections from the five regions (Florida, Maryland, Missouri, New York, and Washington) and examined the behavior of the pedestrian and the accident location, as well as the indigenous conditions. They calculated hazard scores involving pedestrian and vehicle exposure, site characteristics, and accidents as described in Appendix B. A positive score indicates the behavior or feature is more common in the accident reports than the study intersections, while a negative score is less common. Scores between -1.3 and +1.3 are considered to be non-significant. Results showing relevant circumstances are contained in Table 2.2. The data suggests that for intersections with unmarked crosswalks and without controls tend to be more hazardous than marked crosswalks. It should be noted that this work was based on aggregate analysis rather than an analysis of individual intersections. Also, intersections without signals were relatively hazardous, but intersections without any control were even more hazardous. However, when stop signs were provided, those intersections were relatively less hazardous. It is also conceivable that many intersections without marked crosswalks were also intersections without control.

Table 2.2 Selected Hazard Scores

CONDITION	HAZARD SCORE
Intersections without signals	+2.0
Intersections without controls	+2.3
Intersections with Stop control - one street	-1.3
Intersections with 4 way stop - one street	-2.1
Intersections with vehicle signal heads	+1.2
Intersections with vehicle and pedestrian sign heads	-2.4
Intersections with marked crosswalks:	
On both streets	-2.4
On one street	+1.0
Intersections without marked crosswalks	+2.5

Willdan Associates (1986) performed a study of crosswalks and pedestrian safety for the City of Long Beach, CA. Their specific purpose was to determine if the city's Department of Public Works practice regarding marked crosswalks at uncontrolled locations was still appropriate or if it should be changed. In the ten-year study period, there were 499 pedestrian accidents which occurred at uncontrolled intersections in the City of Long Beach. "A total of 440 (88%) occurred within marked crosswalks and 59 (12%) occurred within [unmarked] crosswalk areas. . . . The ratio . . . of pedestrian accidents at uncontrolled intersections between marked crosswalks and unmarked crosswalks was found to be 7.5 to 1.0. The severity of pedestrian accidents in marked crosswalks at uncontrolled intersections was also greater than [the severity] . . . experienced within unmarked crosswalks at uncontrolled intersections. In total, 6% of the initial reports of pedestrian accidents which occurred in marked crosswalks at uncontrolled intersections resulted in fatalities. No fatalities occurred within unmarked crosswalks at uncontrolled intersections based upon review of the initial pedestrian accident reports. The study did not include pedestrian volume counts of the usage of marked and unmarked crosswalks at uncontrolled intersections. However, the City of San Diego found in their 1970 study that there were 2.9 times more pedestrians in marked crosswalks as compared to unmarked crosswalks at uncontrolled intersections. Application of the San Diego pedestrian usage factors to this study [indicate] . . . that marked crosswalks are more likely, by a ratio of 2.6 to 1.0, to produce pedestrian/vehicle accidents than those [uncontrolled] locations with unmarked crosswalks." (Willdan Associates, p. ES-2) Upon review of the results, Willdan Associates recommended to the City of Long Beach that their policy regarding marked crosswalks at uncontrolled locations be retained without modification. This policy states that:

> "Marked crosswalks shall not be installed at uncontrolled locations unless special study by the City Traffic Engineer determines such markings to be necessary and desirable for the specific purpose of encouraging concentration of pedestrian crossings at a certain point." (Willdan Associates, p. ES-3)

Willdan Associates (1986) also reviewed, in summary form, six studies also conducted in Southern California. Four of the relevant studies are summarized below.

County of Los Angeles-1967. "This study involved [a] review of accident information at marked crosswalks at uncontrolled intersections. The database included a total of 550 pedestrian accidents which had occurred within the county unincorporated areas as well as several of their contract cities between 1960 and 1965. In the six year period, the study indicated . . . over twice the number of reported pedestrian accidents [occurred] in marked crosswalks as compared to unmarked crosswalks. This same study also examined accident histories at locations where marked crosswalks had been installed." They found that at 89 uncontrolled intersections, the installation of white crosswalks resulted in a 275% increase in pedestrian accidents. While the before period had only 4 accidents with 5 injuries, the after period had 15 accidents resulting in 17 injuries and 2 fatalities. "They also determined that most of the pedestrian accidents which occurred in the after period occurred at night at locations without lighting. They also determined that vehicle/vehicle rearend accidents increased 87% after the crosswalks were marked, from 31 with 15 injuries in the before period to 58 with 47 injuries in the after period." (Willdan Associates, p. 10)

County of Los Angeles-1974. "This study examined [the] before and after experience of pedestrian accidents at locations where marked crosswalks had been removed from problem intersections which were located 400 feet or less from adjacent signalized intersections. This study found that these marked crosswalk removals had resulted in a 100% reduction in pedestrian accidents and a 95% decrease in vehicle/vehicle rear end collisions following the removals."

County of Los Angeles-1975. "This study examined a number of factors associated with pedestrian accidents. The database included 898 reported pedestrian accidents in the unincorporated area and in contract cities served by the County for a one year period between October 1971 and September 1972. The study determined that over two thirds of pedestrian accidents at non-signalized "T" intersections on arterials occurred in marked crosswalks, with more than half of these in marked crosswalks 600 feet or less from adjacent traffic signals. At four-way non-signalized intersections, more than half of the pedestrian accidents occurred in marked crosswalks. Eighty percent of these accidents occurred on arterials with 61% in marked crosswalks, most of which were within 600 feet of adjacent traffic signals."

<u>City of Long Beach-1977</u>. "The City of Long Beach conducted a study of pedestrian accidents at intersections occurring within the city between 1972 and 1974. This study found that 30% of the pedestrian intersection accidents occurred within marked crosswalks and only 18% occurred at intersections without marked crosswalks. [Because] . . . the number of locations with marked crosswalks [are] about one fifth of those without marked crosswalks, the study indicated an accident frequency rate of marked crosswalks as being 8.3 times greater than those locations [with unmarked] crosswalks. While no pedestrian utilization counts were made, it was assumed [by the city] that pedestrian usage in marked crosswalks was 4 times greater than that within unmarked crosswalks. This study concluded that marked crosswalks are more likely, by a 2 to 1 ratio, to produce pedestrian/vehicle collisions." (Willdan Associates, p. 11)

Daly, McGrath, and vanEmst (1991) were involved in research directed toward the revision of the criteria for the installation of pedestrian crossings in England. In their report, they discussed the accident rate at sites where no pedestrian crossing facility existed and the accident rate after either a pelican, zebra, or refuge crossing was put in place. The essential difference between a zebra and a pelican crossing is that a pelican controls both the vehicular and pedestrian traffic by traffic signals, whereas, pedestrians are given priority over vehicles at zebra crossings. Fifty "no crossing" sites, similar to the sites where a pedestrian crossing was to be placed, were used to obtain an average number for pedestrian/vehicle conflicts. "Pedestrian flow data were collected before and after the installation of crossing facilities at 16 zebra crossings, 22 pelican crossings and 19 refuges. These data were used to assess the impact of crossings on levels of pedestrian activity. . . . Accident data for 3 year periods before and after the installation of new crossing facilities were provided by local authorities for 38 zebra crossings, 109 pelican crossings and 57 zebra to pelican crossing conversions. Accident data covering a 3-year period were also assembled for 50 baseline or 'no crossing' sites. These accident data, together with site flow and layout characteristics, were used to establish accident frequency models. . . . At the 204 sites for which before and after accident data were collected, a reduction of some 18% in the total number of accidents occurred between the 3 year periods before (877 accidents) and after (736 accidents) the introduction of the new facility. Within this total change, pedestrian accidents decreased by some 28%, reducing from 371 to 266, and non-pedestrian accidents by only 11% (526 to 470 accidents). . . . There was some suggestion that the introduction of crossing facilities had a greater [positive] impact on accident levels in adverse conditions: accidents in the dark reduced by 28% (281 to 203) compared with a 14% reduction for accidents in the light (616 to 532); wet weather accidents decreased from 317 to 247, a 22% reduction, compared with a 15% reduction (572 to 486 accidents) for dry conditions." (Daly et al., p. 29) Note that these crossing facilities improvements introduced were not simply the marking of a crosswalk that is the focus of this study.

2.7 POLICIES OF OTHER AGENCIES IN SOUTHERN CALIFORNIA

Willdan Associates (1986) included as part of their study a discussion with other agencies in Los Angeles and Orange Counties regarding their policies and practices related to marked crosswalks at uncontrolled locations. They contacted eleven agencies, including the City of Long Beach, in these two counties which represented populations greater than 100,000. "The ten other agencies were chosen jointly with city staff as agencies to be contacted during this study as it was believed that they had pedestrian, roadway and land use characteristics similar to the City of Long Beach. . . ." (Willdan Associates, p. 12) Some of the questions asked of the representatives of these agencies were: "Describe your present policy and practice regarding marked crosswalks at uncontrolled locations, describe your basis for this policy and practice, and how long [it] has . . . been in effect." The summarized results they received back from these agencies were:

> "1. In regard to policy, each of the ten agencies have [sic] a policy to remove marked crosswalks at uncontrolled locations. Most agencies accomplish these removals with resurfacing projects in that the marked crosswalks are not restored after the project is completed.
>
> 2. Regarding the basis for this practice, each of the ten agencies indicated an awareness of the City of San Diego study. In addition, other agencies use a combination of their local experience together with the previous study prepared by the City of Long Beach as justification.
>
> 3. Most agencies have had this policy for several years, with one agency following this course of action since the late 1960's." (Willdan Associates, p. 12)

They also determined that most agencies in California use the Traffic Manual published by the State's Department of Transportation as a guideline for their local traffic engineering matters.

2.8 GUIDELINES OR WARRANTS

The goal of the project by Knoblauch, Smith, Tustin, and Pietrucha (1988) was to develop a set of guidelines based on current research information that would be accepted and used by the practicing traffic engineer. Before the project began, no assumption was made by the authors of that study as to whether marked or unmarked crosswalks were safer. The project undertaken by the aforementioned was commissioned by the Federal Highway Administration (FHWA) because of a previous FHWA study done by Tobey, Shunamen, and Knoblauch (1983) based on pedestrian exposure. The study identified the relative hazard associated with many characteristics of pedestrian accidents. Four problems areas, "intersections without marked pedestrian crosswalks, major arterial streets, local streets, and locations lacking sidewalks or pedestrian pathways" identified in this earlier study (Tobey 1983) were selected because they were areas considered to offer promise for accident reduction. (Knoblauch et al., p. 1)

Part of the project by Knoblauch et al. (1988), investigating exposure based pedestrian accident areas, was to develop a set of draft guidelines for determining which type of markings should be provided. As reported by Smith and Knoblauch (1987), ". . . the draft guidelines were based on current practices as identified during a literature review, a survey of local practitioners, and an examination of relevant pedestrian research. The guidelines were not based on either pedestrian accident occurrence or pedestrian-vehicle conflicts. The draft guidelines were reviewed by about 30 practitioners and, on the basis of their comments, a final set of guidelines was prepared. . . .

"Practicing traffic engineers in nine geographically diverse state and municipal agencies were contacted to determine current operational practices pertaining to the installation of crosswalk markings. Each practitioner was asked specific questions involving:

- Warrants, guidelines, and criteria used for installing marked crosswalks,
- Any problems involved in applying those warrants,
- What factors or criteria should be considered in developing non-crosswalk warrants.

It was found that very few of the respondents used specific quantitative procedures for the application of crosswalk markings. All of the respondents marked crosswalks on school routes and most marked crosswalks at signalized intersections. Several of the respondents used "point" warrant systems to rank locations by priority for crosswalk installations. Although three respondents indicated that they considered pedestrian volumes when installing crosswalks, only one quantified the minimum pedestrian volume warrant at 100 pedestrians/day. Most of the respondents believed that factors such as vehicle volumes, pedestrian volumes, vehicle speed, school children, and sight distance should be included in a new crosswalk warrant. At the same time, the practitioners cautioned that the new crosswalk warrants should not require extensive additional data collection. . . .

"Several other sources of information were used for establishing the initial set of guidelines. The first source consisted of data from the study of pedestrian exposure by Tobey, et al." (Smith and Knoblauch 1987, see also Appendix B). Another source of information " . . . analysis involved a comparison of scatter diagrams of pedestrian vehicular volumes at marked and unmarked crosswalks. It was hypothesized that one would find that crosswalks were marked at locations with higher pedestrian and vehicular volumes and not marked at locations with lower volumes. Although this was true in general, there was considerable overlap in the volume levels for marked and unmarked crosswalks. Marked crosswalks were sometimes found at very low volume levels, and unmarked crosswalks were found at high volume levels. . . .

"The data . . . provide an indication of how practitioners and decision makers have, in the past, determined where crosswalks should be marked. If one makes the assumption that their judgment is reasonably good, an analysis of the data could be performed to derive an optimum volume threshold curve to use as part of the crosswalk guidelines. This analysis was conducted by fitting several trial curves through the data and identifying which curve minimized alpha and beta error. Alpha error would exist when a marked crosswalk volume was below the volume threshold curve. Beta error would exist when an unmarked crosswalk volume [was] above the volume threshold curve. . . .

"A second source of information used in establishing the volume threshold curves consisted of existing warrants from outside the United States. [A figure in that study] prepared for a South African study, indicates warrant threshold curves proposed or already in use in Australia, Israel, and South Africa for vehicles and pedestrians at mid-block pedestrian crossings." (Smith and Knoblauch, pp.16-17) Using this information a basic threshold curve was established. This basic threshold curve is provided in the Smith and Knoblauch study. Additional curves were established with lower thresholds to cover wider streets and locations with higher proportions of young, elderly, and handicapped pedestrians. These curves can also be found in the Smith and Knoblauch study.

"The information gathered during the practitioner survey and the analysis of relevant research were used to generate a preliminary series of warrants for crosswalk markings. Through an iterative process, a draft set of guidelines that was intended to be both responsive to the needs of local practitioners and sensitive to the available research was developed. This draft was sent to 30 practitioners from the engineering and research community for their review. The individuals were selected from the Markings Technical Subcommittee of the National Committee on Traffic Control Devices and the Committee on Pedestrians of the Transportation Research Board. . . .

"The review by practitioners involved sending out the draft guidelines along with a set of questions used to evaluate various aspects. The questions asked were; 'Are such guidelines needed?', 'Will the guidelines benefit state and local agencies?', 'Is the format usable?', 'Is the concept of a volume based warrant valid?', 'Are the thresholds reasonable?'

"Responses by the reviewers were generally positive. There was a consensus that the guidelines were needed, and there appeared to be no major concern with overall approach. Reviewers believed that both the basic criteria and the volume based thresholds were appropriate. . . . Some reviewers believed that the guidelines would result in the marking of more crosswalks, whereas, others believed that fewer would be marked. The majority, however, thought that the guidelines would result in the marking of about the same number. The comments and suggestions made by the reviewers were considered when the final set of guidelines was prepared." (Smith and Knoblauch, pp. 18-19)

Before giving their final guidelines, Knoblauch et al. (1988), reviewed the basic principles on locating crosswalk markings that served as the foundation for the draft of the final guidelines.

In another article Smith and Knoblauch (1987) present their recommended guidelines as well as a discussion by Herms. In his discussion, Herms gave his analysis of their guidelines by reviewing each guideline and giving his opinion of its effectiveness. If both discussions were not presented, this paper would be far from complete. It appears that both parties have put forth considerable time and effort in creating a set of guidelines for the installation of marked crosswalks.

2.9 POINT SYSTEM VERSUS GRAPH SYSTEM

Herms' discussion of the guidelines presented by Smith and Knoblauch (1987) points out that they utilize the same basic warrants as San Diego. However, the difference in the two approaches is that San Diego uses a point system, whereas, Smith and Knoblauch use a graph. San Diego requires ". . . 16 of 28 possible points to qualify for the installation of a marked crosswalk. These points are obtainable under 3 categories: . . . pedestrian volume, . . . general conditions, . . . and gap time. . . . Pedestrian volume ranges from 2 points for 11 pedestrians crossing per peak hour to 10 points for over 100 pedestrian crossing per peak hour. . . . Up to 8 points are provided for improved channelization considerations. . . . The warrant for gap time provides for up to 10 points based on the average number of safe gaps per [five minute] period available to permit the pedestrian to cross the street without being in conflict with a vehicle. . . ."

Herms states that the general concept of a nomograph is good and that the basic values appear to be reasonable. However, he says that both the point system and the nomograph must be used with caution. He suggests ". . . that the cut-off points or, in the case of the nomograph, the demarcation or decision line is not always as clearly defined as it may seem. Rather than a sharp line there is a blurred zone where conditions could go either way." He goes on to suggest that ". . . when warrants or guidelines are applied, good engineering judgment based on experience and knowledge of the site are important aspects of the decision-making process." (Smith and Knoblauch, p. 22.)

Smith and Knoblauch state that " . . . although point systems have been widely used in the transportation industry, [they] believe it introduces a temptation for the engineer to be more lax in thinking through all the factors [which] should be considered." They suggest that using the point system " . . . can more easily become a cookbook approach than will a nomograph threshold approach. . . . A point system can bring all [these] important factors into consideration, but it becomes too easy for the engineer to be removed from personally thinking through the pros and cons of each situation and there is no assurance that the weights assigned in the point system reflect . . . the most important factors." They do, however, " . . . caution that just because a location passes the minimum volume thresholds in [their] graph system, it does not mean that a crosswalk is automatically warranted. There are . . . transitional areas that could be decided either way, depending on other factors." (Smith and Knoblauch, p.24.)

2.10 ADVANTAGES, DISADVANTAGES, AND RECOMMENDATIONS

Herms (1972), at the conclusion of his article reviewing the study that took place in San Diego, proposes that there are some advantages and disadvantages to marking crosswalks. He also gives some recommendations at the end of this article. "In general, marked crosswalks have the following advantages:

1. They may help pedestrians orient themselves and find their way across complex intersections,

2. They may help show pedestrians the shortest route across traffic,

3. They may help show pedestrians the route with the least exposure to vehicular traffic and traffic conflicts,

4. They may help position pedestrians where they can be seen best by oncoming traffic,

5. They may help utilize the presence of luminaires to improve pedestrian nighttime safety,

6. They may help channelize and limit pedestrian traffic to specific locations,

7. They may aid in enforcing pedestrian crossing regulations,

8. They may act, in a limited manner, as a warning device and reminder to motorists that this is a location where pedestrian conflicts can be expected.

Marked crosswalks also exhibit some disadvantages:

1. They may cause pedestrians to have a false sense of security and to place themselves in a hazardous position with respect to vehicular traffic,

2. They may cause the pedestrian to think that the motorist can and will stop in all cases, even when it is impossible to do so,

3. They may cause a greater number of rear-end and associated collisions due to pedestrians not waiting for gaps in traffic,

4. They may cause an increase in fatal and serious-injury accidents,

5. They may cause an increase in community-wide accident insurance rates,

6. They may cause a disrespect for all pedestrian regulations and traffic controls,

7. . . . [they] may cause an increased expense to the taxpayers for installation and maintenance costs that may not be justified in terms of improved public safety." (Herms, p. 12)

The recommendations given by Herms for the placement of marked crosswalks are:

"1. Existing crosswalk warrants should be reviewed and updated. Special consideration should be given to pedestrian channelization needs, nighttime illumination, vehicle approach speed, and motorist inability to see pedestrians or the crosswalk at the critical safe stopping distance,

2. No new crosswalks should be installed unless they meet the conditions established by the warrants,

3. Existing crosswalks should be reevaluated to see whether they meet the revised warrants,

4. Efforts should be made to re-educate pedestrians regarding the limitations of the marked crosswalks and to alert them to some of the special hazards that they may encounter while crossing streets,

5. Attention should be given to the long-range needs of the pedestrian when planning new communities and developing existing communities in order to reduce the conflict between pedestrian and vehicle,

6. Research should be continued on a national scale to gain a better understanding of the pedestrian safety problem and to seek workable solutions and alternatives to the problem." (Herms, pp. 12-13)

2.11 SUMMARY

Unless the crosswalk marking dimensions are given, it was assumed that they were the standard 300 millimeters (12 inches) wide marking lines. This assumption was made because in most of the articles the dimensions of the crosswalk markings being studied were not given.

There is a need to make a specific set of guidelines which the practicing traffic engineer can use to make sound decisions for the placement of marked crosswalks. Too many times marked crosswalks are placed due to public pressure. However, specific guidelines would help reduce the number of marked crosswalks which are placed because of public pressure. This would help decrease the number of marked crosswalks placed in improper situations. Besides the guidelines, the engineer must learn to use good engineering judgment based on experience and sound principles.

Several guidelines have had some acceptance but a complete layout of guidelines has yet to be accepted by the majority of practicing traffic engineers. Most states and cities tend to make their own guidelines. This discourages uniformity between different states and cities. This lack of specific guidelines has caused some engineers to try and draft a set of accepted guidelines. However, the task has been difficult. There is not a great deal of data available to help in this task. More research needs to be done to provide more reliable data.

As can be seen in the case studies presented in this report, there are some studies that would indicate a need for a reduction in the use of marked crosswalks, however, there are some studies that indicate the opposite. This inconsistency has helped fuel the debate as to whether or not marked crosswalks benefit the general public. A noteworthy shortcoming in many of the studies is that comparisons are made between numbers of accidents and fatalities and seem to fail to take into account the exposure or opportunity for an accident to happen as would be the case if a rate (e.g., accidents per million crossings) were used to reflect exposure. More specific research will help provide the answers to these questions.

Two facets of pedestrian safety that need to be more fully explored are education and enforcement. Studies in the area of enforcement seem to be lacking with respect to pedestrian safety. Studies have been done concerning the effects of education on pedestrian safety. All the studies have given positive results. Children have been tested the greatest amount and have performed remarkably well when instructed about pedestrian safety. However, more study needs to be done on whether or not this information or behavior will stay with the child. Also more studies need to be done to determine the effects of education on adults and young adults concerning pedestrian safety. Studies in this area seem to be lacking.

There is some inconsistency in the literature about the safety merits of marking crosswalks. Studies in San Diego and Long Beach concluded that accident experience is worse for marked crosswalks at unsignalized intersections. However, a FHWA supported study concluded that crosswalks in general are "less hazardous" if markings are present. It should be noted, however, that this study included uncontrolled intersections, many of which will have unmarked crosswalks. Stop controlled intersections were less hazardous.

To conclude, crosswalk markings can be a useful traffic control device, but it is important the public recognize the negative as well as the positive consequences of marking crosswalks. The review of the literature suggests that public officials should carefully consider whether the anticipated benefits outweigh the potential risks when considering crosswalk treatments.

3.0 SELECTION OF STUDY INTERSECTIONS

3.1 INTRODUCTION

The purpose of the intersection selection process was to develop a representative and unbiased sample of intersections throughout the more populous Caltrans districts in order to study the safety of marked pedestrian crosswalks. The nine districts used for this study are shown in Table 3.1. District's 1, 2, and 9 were not used because they were

Table 3.1 Caltrans Districts Included in this Study

District	Office Location
3	Marysville
4	San Francisco (Oakland)
5	San Luis Obispo
6	Fresno
7	Los Angeles
8	San Bernardino
10	Stockton
11	San Diego
12	Santa Ana

considered too rural for the purposes of this study. It should be noted the intersection selection was done in such a way as to remove conditions (i.e., the presence of schools) that might interfere with assessment of the effect of marked crosswalk presence or absence on pedestrian safety. The intersections were only random with respect to the presence or absence of any pedestrian accidents. In other words, the selection process was blind to all intersection accident histories. The multi-level intersection selection process yielded a large sample of intersections that appear to be good candidates for inclusion in this study. A portion of these intersections was selected for pedestrian counts. The process for their selection will also be discussed within this chapter.

Due to the number of intersections involved, a multi-level selection process was designed in order to reduce the total number of state highway intersections in nine Caltrans districts to a manageable number. These included both intersections both 1) between two state highways and 2) between a state highway and a local street. The first level selection was based on information obtained through the Traffic Accident

Surveillance and Analysis System (TASAS) computer database, as well as aerial and photolog information available at Caltrans Headquarters in Sacramento. The second level was based on the intersection crosswalk configurations. The third level was based on population and elevation considerations. Pedestrian counts were accomplished using the third level population as a basis for reasons discussed in Section 3.5 of this report. The fourth level selection was based on changes in intersection type, control type, lighting or primary street. Finally, the fifth level selection was predicated on control type, leaving roughly half of the final total of 380 intersections of the signalized type, and the remaining of the stop controlled type.

3.2 FIRST LEVEL

A request was made through the TASAS database to select all urban intersections with certain intersection controls for all state routes in nine Caltrans districts. The intersections were restricted to the controls shown in Table 3.2. From these computer

Table 3.2. Intersection Controls Allowed in This Study

Control Type	Details
None	-
Stop Sign	Minor Approaches Only
Signals	Fixed Time
	Semi-Actuated, Two-Phase
	Semi-Actuated, Multi-Phase
	Actuated, Two-Phase
	Actuated, Multi-Phase

lists all four-legged intersections were selected for further examination at Caltrans Headquarters. The aerial photographs of the routes, on file at Headquarters, were used to study the four-legged intersections and the immediate area surrounding them. These aerial photographs were taken from aircraft contracted to fly the state routes in order to catalog the two dimensional view of the route and surrounding areas. In more rural areas the photographs encompass an area within 0.8 kilometers (0.5 miles) of the route while in urban areas between two and three standard-sized city blocks are shown on either side of the route. From the aerials, the crosswalk configuration was determined based on, to the extent possible, the proximity of the four-legged, urban intersections to schools, hospitals, and fire stations. Any four-legged urban intersections within two linear blocks of any of these facilities were removed from further consideration. It was concluded that these type of facilities could produce pedestrian trips and pedestrian accidents with unusual characteristics which could mask the effect of marked crosswalk presence or absence on pedestrian accidents. Some concerns were rapid movement of emergency vehicles, street crossing by people either unfamiliar with traffic laws (children) or preoccupied with other matters (family or friends of patients, for example).

In addition to the placement of crosswalks, the aerials were also used to determine the lane assignments for each approach, the presence and location of islands, as well as pedestrian refuges. For convenience in data collection, the top of the aerial was always defined as 'north' for both south/north and west/east routes. This was done because the postmile designations always increased from the bottom of the photograph to the top. (Data available from TASAS on each route allowed for the eventual rotation of the intersection into its true orientation after all levels were completed).

After the aerial photographs were studied, the remaining intersections were examined through the photolog. Photologs are a series of continuous-film photographs (approximately 30.5 meters [100 feet] per frame) taken from a camera-equipped Caltrans van. State routes are filmed once every two or three years. The routes are filmed in both directions and are on separate reels that can be run side by side. The purpose of using the photologs was to examine the sight distance along the main route for each of the intersections still under consideration thus far. Only intersections with good sight distance of at least 30.5 meters (100 feet) were considered acceptable on low speed cross streets. The posted speed limit was taken into account in considering questionable sight distances. Any intersection that was felt to have poor sight distance due to geometrics, parking restrictions or allowances, or placement of permanent fixtures -- such as newspaper boxes, trees, signal or lighting poles, telephone poles, or signal timing boxes -- were removed from the study.

Although most school facilities were easy to spot on the aerials, hospitals and fire stations often were not so easy to locate using the aerials. Usually these facilities were discovered through sign references found during the photolog examination. If such a facility was discovered during the photolog examination the necessary aerials were reexamined in order to locate the facility in relation to the intersection in question.

The result of the first level was a reduction of candidate intersections from an initial potential sample of 10,710 sites to 2,116 selected intersections. This was a reduction of 80%. Each district showed a reduction in candidate intersections between 17% and 28% of the original number. Concerning intersection control types, those intersections with no control suffered the greatest reduction, going from 461 intersections to one found in District 7. The second greatest reduction occurred with intersections under stop control on the minor approaches. This intersection type dropped from 72% of all intersections to 47%.

3.3 SECOND LEVEL

In the second level the deciding factor for further inclusion was the placement of crosswalks. For the purpose of this study the following crosswalk configuration groups were retained: 1) No marked crosswalks, 2) one marked crosswalk on a major approach, 3) one marked crosswalk on a minor approach, 4) crosswalks on both major approaches, 5) crosswalks on both minor approaches, and 6) crosswalks on all four approaches. It was concluded that these crosswalk configuration groups would make it easier to determine the effect of marked or unmarked crosswalks on pedestrian safety. Any other crosswalk configuration was excluded by this level. The presence or proximity of islands to any of the crosswalks, refuges, or different crosswalks such as zebras were not considered for this level. The frequency of use was simply too rare.

A total of 321 intersections were removed from the database based on crosswalk configuration resulting in 1,795 intersections remaining for further consideration.

3.4 THIRD LEVEL

The third level was based on population and elevation criteria. Cities or unincorporated areas with a population fewer than 5,000 or elevations higher than 1220 meters (4,000 feet) would be excluded from further consideration. The population restriction was implemented because small cities or unincorporated areas might not have enough consistent pedestrian levels to warrant their inclusion in this study. The elevation restriction was effected to exclude any intersections above the snow line from inclusion in the final sample population. To determine the population and elevation of the intersections area it was associated with a geographic place name. If an intersection could not be located to a place name it was deleted. The 1989 edition of the Department of Transportation's Place Names In California was used as the population and elevation source for each identified place name. All incorporated city populations listed within the booklet are 1988 estimates based on the 1980 federal census. For the unincorporated areas the population figures are either from the 1980 census or from local sources.

Under the population and elevation constraints, a total of 231 intersections were removed from the study, leaving a total of 1564 intersections. These reductions occurred mostly (71%) in the mountainous and more rural Districts 3, 5, and 8.

3.5 PEDESTRIAN COUNT INTERSECTION SELECTION PROCESS

The purpose of the pedestrian counts was to determine the pedestrian usage of intersections based on intersection location (urban, rural, or suburban) and to the extent the crosswalks were present. To do this, 211 intersections were selected for counting from the 1,564 third level intersections. In order to schedule the pedestrian count before the effects of holiday shopping would be detected, it was necessary to use the third level population. Waiting for the fourth level would have made the counts too late in the year and the count would have been postponed nearly six months. The basis for their selection was district assignment and urban, suburban, or rural designation, as described below.

Caltrans uses federal codes based on population densities and city limits, as determined from the prior federal census, to designate intersection locations as urbanized, urban, suburban, or rural, shown in Table 3.3. For convenience in this study, the urbanized and urban designations were combined as simply urban. Ten categories of the federal code are designated as urban (included urbanized). Of these, five were frequent enough in the third level group to each represent more than 1% of the total. Eleven categories of the federal code are designated suburban. Of these eleven, two categories each represented more than 1% of the third level database. The last designation, rural, is represented by three codes, of which one represented more than 1% in the third level database.

In order to select a group of intersections that would be representative of both the number of intersections in the district and the federal urban, suburban, or rural designations of these intersections, the following process was used. Totals of each of the eight federal codes in the nine districts were determined. The totals were then placed in a table with the districts representing the rows and eight federal designations as the columns. The table was then proportionally reduced until the total number of intersections was 211. Some adjustments were made between rows (but not between columns) when changes had to be made. For instance, no counters could be found for

Table 3.3 Federal Code Designations

Code	Description	Designation
Rural Development < 5000 Population		
A	Inside city	Suburban
B	1/2 inside city, 1/2 outside city	Suburban
C	1/2 inside city, 1/2 inside adjacent city	Suburban
D	1/2 inside city, 1/2 inside county	Suburban
E	Independent alignment one direction inside city, other direction inside county	Suburban
F	1/2 inside county, 1/2 inside adjacent county	Rural
G	Outside city	Rural
H	Independent alignment one direction in county, other direction in adjacent county	Rural
Urban Development > 5000, < 50,000 Population		
J	Inside city	Urban
K	1/2 inside city, 1/2 outside city	Urban
L	1/2 inside city, 1/2 inside adjacent city	Urban
M	1/2 inside city, 1/2 inside county	Urban
N	Independent alignment one direction inside city, other direction inside county	Urban
P	1/2 inside county, 1/2 inside adjacent county	Suburban
Q	Outside city	Suburban
R	Independent alignment one direction in county, other direction in adjacent county	Suburban
Urbanized Development > 50,000 Population		
S	Inside city	Urbanized
T	1/2 inside city, 1/2 outside city	Urbanized
U	1/2 inside city, 1/2 inside adjacent city	Urbanized
V	1/2 inside city, 1/2 inside county	Urbanized
W	Independent alignment one direction inside city, other direction inside county	Urbanized
X	1/2 inside county, 1/2 inside adjacent county	Suburban
Y	Outside city	Suburban
Z	Independent alignment one direction in county, other direction in adjacent county	Suburban

hire in District 12 (Santa Ana) so the row totals were added to the District 7 (Los Angeles) row totals. This was done because District 12 and 7 share similar population, elevation, and demographic characteristics. Any changes made to the table were made with these same considerations. Changes were only made based on the availability of counters.

Each intersection to be counted was assigned a date for the count during a two week period November 9 - 20, 1992. To avoid unusual pedestrian traffic flows, counts were done Monday through Thursday so as to exclude the weekend. Since a preliminary pedestrian accident report for 1991 had shown that pedestrian accidents were fairly stable between 3:00 P.M. and 7:00 P.M., the counts were to be done from 3:00 P.M. to 6:00 P.M. Each counter hired was given as much information as possible in order to locate the intersections assigned to them. In each district, Caltrans personnel oriented the local team of counters on the use of the required pedestrian count forms and safety issues that would concern them while in the field.

A final number of 174 intersections had successful counts completed at them. The discrepancy between the 211 scheduled counts and the final 174 are shown in Table 3.4. The 13 intersections where no counters were available were all located in District 12 (Santa Ana). Although the intersections selected for the count were substituted for in District 7 (Los Angeles), not enough people could be hired to cover them there. Of the sites where counts were either poorly done or not done, two were simply not counted because the counter could not find the location and the remaining 6 showed systematic errors indicating that the counts were not conducted during the full period.

Table 3.4. Breakdown of Intersection Counts.

Intersection Count Result	Number
Successfully Counted	174
No Counters Available	13
Work Poorly or Not Done	8
Wrong Location Counted	2
Work Not Picked up by Counter	14
Total	211

3.6 FOURTH LEVEL

In the fourth level of the selection process, any intersection which showed a date of change on the Caltrans data records under intersection type, control type, lighting, or mainline between January 1, 1987 and December 31, 1991 was removed. This affected 137 intersections, leaving a balance of 1427 intersections. Although the nature of the changes for each specific intersection was not known when they were removed, these change dates generally indicate that large changes have occurred at these sites. Consequently, the intersection which underwent change could not be considered stable during the study period.

3.7 FIFTH LEVEL

The final step, the fifth level intersection selection process, yielded 380 intersections, roughly half of which were signalized, while the other half were stop controlled. Attempts were made to keep the crosswalk configurations present in each group at a statistically significant level. The 380 intersections were the most which could be accommodated within the project budget. While the groups were "blocked", or separated by control and crosswalk configuration, the intersections were randomly selected from each group.

A total of 55 of the 174 counted intersections from § 3.3 remained in the final 380 intersections.

The full 380 intersections selected were considered for selection subject to clearing in-district review. Records which were consulted were signal timing logs, sign records, and intersection work order records. If these records indicated the intersection was stable for the five years of the study period, it was retained. If not, it was removed and a replacement randomly drawn from the reserve intersections.

3.8 SUMMARY

The overall result of the multi-level process was a reduction of candidate intersections from 10,710 initial sites to 1,427 four-legged intersections with good sight distance, geometrics, and crosswalk configurations. These remaining candidate intersections were also in larger urban areas and below the snow line. Table 3.5 shows the number of urban intersections at each level on a per district basis. The final totals for each district range from 4% (District 3) to 21% (District 7) of the initial intersections, by district.

Table 3.5 Number of Intersections at After Each Step by District

District	Initial Number	Number of Intersections After: First Level	Second Level	Third Level	Fourth Level	Fifth Level
3	1,823	276	213	138	117	43
4	2,005	368	283	265	260	77
5	1,087	189	172	129	124	41
6	719	203	194	170	167	31
7	2,456	447	374	365	299	78
8	1,059	258	230	184	171	34
10	470	112	100	95	86	29
11	109	133	125	117	110	31
12	529	130	104	101	93	16
Total	10,710	2,116	1,795	1,564	1,427	380

4.0 DATA COLLECTION

4.1 INTRODUCTION

The purpose of the data collection was to retrieve sufficient intersection information to analyze the safety of the selected intersections. A total of 380 intersections were selected from Caltrans Districts 3, 4, 5, 6, 7, 8, 10, 11, and 12. The other districts did not have sufficient concentrations of intersections to make traveling to them feasible. Additionally, the pedestrian volumes would likely be very low. Table 4.1 contains a breakdown of the number of intersections that were selected from each district. This section describes the data collection activities.

Table 4.1 Selected Intersections Listed by District

District	Number	Percent
3	43	11.3
4	77	20.2
5	41	10.8
6	31	8.2
7	78	20.5
8	34	8.9
10	29	7.6
11	31	8.2
12	16	4.2

Since the data collection effort involved costly travel to various sites in California and some uncertainty existed as to specific analysis needs, the designed database was very comprehensive. The intent was to collect all data which <u>might</u> be needed with only one trip to the districts. Once the analysis had begun, it was apparent that some data needed to be aggregated because some classifications did not provide a sufficient number of observations.

The data collection efforts for this study were accomplished in four phases. The first phase involved the retrieval of intersection characteristics from the TASAS database for the study. The second phase consisted of obtaining vehicular volumes and pedestrian volumes at the intersections selected for the study. The third phase concerned the pedestrian-related accidents which occurred at the selected intersections between 1987 and

1991. The fourth phase identified changes at these selected intersections which may have affected pedestrian safety. A database was structured to accommodate additional blocks of data formed by individual fields. This data structure, developed in dBASE 3+ included: 1) intersection characteristics from TASAS, 2) vehicular volumes and pedestrian volumes 3) accident data and 4) information on changes occurring at the selected intersections. Data collection methodologies for each phase will be described in more detail in the following sections. The following narrative generally describes the various fields.

4.2 PHASE I - INTERSECTION INFORMATION FROM TASAS

The first block of information was centered on the location and configuration of the intersections. The location of each intersection was defined using the following information:

1. District
2. County
3. Route
4. Route-Modification
5. Postmile-Modification
6. Postmile
7. City
8. Population
9. Elevation
10. Description
11. Date Established

To completely identify an intersection, the district as well as the county, route, and postmile must be known. This information was retrieved from the TASAS database. The route and postmile modifications are denoted by a letter which is a letter modification of the route number and postmile, respectively. Other data which was collected to define the location of the intersection included 1) the city in which it is located, 2) the city's population, and 3) the city's elevation. The description of the intersection is simply the name of the cross-street. The "date established" is the date when the intersection was either constructed or entered into the TASAS database.

To define the configuration of the intersection additional data was collected which included the following:

1. Improvement Date
2. Number of Lanes
3. Dominant Flow
4. Crosswalks
5. Intersection Control
6. Bus Stop

Up to a maximum of four improvement dates were collected for each intersection. These construction dates are noted in TASAS files and indicate some change occurred at an intersection. The "Number of Lanes" category contained the number of through, left, and right lanes for all directions. The dominant flow of the intersection was identified as either straight or angled. If the state highway was found to make a turn through the intersection, then the intersection was classified as angled. There were five different types of crosswalks found in the data collection. A crosswalk was either 1) Present with the standard two parallel lines, 2) Non-existent, 3) Present with islands, 4) Present with crosswalks from island to island then to sidewalk, or 5) Present with brick or zebra lines. Crosswalks, if noted, were collected on all North, South, East, and West approaches. To avoid confusion with directions the increasing milepost direction was designated "north" for north-south routes and "north" for east-west routes as well. After data was collected only types 1 and 2 provided enough observations for the purpose of analysis.

The types of intersection control were 1) no control, 2) stop sign on minor, 3) signal pre-timed two-phase, 4) pre-timed multi-phase signal, 5) semi-actuated two-phase signal, 6) semi-actuated multi-phase signal, 7) fully actuated two-phase signal, and 8) fully actuated multi-phase signal. Whether or not a bus stop was present at the intersection was also noted.

4.3 PHASE II - VEHICULAR AND PEDESTRIAN VOLUMES

In order to incorporate pedestrian exposure analysis, it was necessary to obtain data on the number of motor vehicles and pedestrians utilizing the intersections that were selected. The vehicular traffic volumes were obtained from Caltrans but pedestrian field counts were required.

4.3.1 VEHICULAR VOLUMES

Vehicular volumes for all 380 intersections were obtained from the 1989 Traffic Volumes on California State Highways published by Caltrans. The average daily traffic (ADT) was obtained using the district, county, route, and postmile for each intersection. If the manual did not have the exact postmile, as was the case for many intersections, interpolation between postmiles was performed. No attempt was made to obtain traffic count data on intersecting cross streets.

4.3.2 PEDESTRIAN VOLUMES

Since pedestrian volumes at intersections were not available from existing sources, field counts were necessary. Of the 174 intersections which were successfully counted, 55 were among the final 380 intersections. No intersections were counted in District 12 (Santa Ana) due to difficulties in finding personnel to perform the counts. The goal of the field counts was to proportionally distribute pedestrian counts among each district and to assess pedestrian usage based on crosswalk configuration.

Field Counts

Field counts were conducted on predetermined intersections. Only those pedestrians that crossed within the crosswalk lines or within 1.5 meters (5.0 feet) of those lines at the intersection were counted. Many intersections do not have marked crosswalks. In that case an extension of the sidewalk was used to determine the width of the unmarked crosswalk. The count personnel (observers) were to locate a stationary observation site away from any type of vehicle and/or pedestrian flow. Each count was conducted between the hours of 3:00 PM to 6:00 PM on a Monday, Tuesday, Wednesday, or Thursday. These three hour counts were subdivided into 15 minute intervals for counting pedestrians.

Field sheets and intersection diagrams were issued to each observer. The field sheet contained the north, south, east, and west approaches from which pedestrian flows could be recorded. Each intersection diagram displayed the general configuration of each intersection. Intersection details including both major and minor approaches, lane configuration, crosswalk markings, and signs restricting pedestrian crossing were to be drawn in by the observers.

Count Personnel (Observers)

Most observers were local college students hired through the University Foundation in Chico. The time period from 3:00 P.M. to 6:00 P.M., Monday through Thursday, was selected for the pedestrian counts. This time interval is when the highest rate of pedestrians would probably use crosswalks. Counts later in the evening could also have placed the personal security of the observers at risk.

Instructions and Training

Brief training and orientation meetings were conducted with the observers. Except for CSU, Chico students and those in Sacramento all orientation meetings were conducted by Caltrans personnel. Detailed instructions were given to all observers. These instructions familiarized the observers with pedestrian traffic counts and how they should be conducted.

4.4 PHASE III - ACCIDENT DATA

The third phase consisted of the collection of accident data. In each of the nine Caltrans districts, law enforcement agency collision reports for pedestrian-involved and pedestrian-influenced accidents were studied. The following is a list of information gathered from these reports.

1. Date and Time
2. Severity
3. Types of parties involved
4. Movements of parties prior to collision
5. Type of collision
6. Weather, road surface, and lighting conditions
7. Impairments (i.e. alcohol, drugs)
8. Point of impact
9. Party at fault

Data from accidents between 1987 and 1991 were included in the data base. The date and time of each accident was recorded. The severity for each accident was recorded as one of the following: 1) Fatal, 2) Injury, 3) Property Damage Only, or 4) No damage. As expected virtually all accidents were either fatal or injury.

The parties were recorded as one of two types. The first type, pedestrian parties, included 1) No pedestrian present, 2) Pedestrian walking, 3) Pedestrian on skateboard, 4) Pedestrian in wheelchair, 5) Pedestrian running, and 6) Pedestrian stopped. From the data nearly all accidents were of the first two categories. Consequently, for analysis purposes either the present or absence of pedestrians were the only categories used. The second type, vehicular parties, included: 1) Passenger cars, 2) Motorcycles, 3) Pickup and panel trucks, 4) Large truck and truck tractors, 5) Bicycles, and 6) Other types of vehicles.

The movements of the pedestrians and/or vehicle(s) prior to collision included: 1) Stopped, 2) Proceeding straight, 3) Veering left or right, 4) Making right turn, 5) Making left turn, 6) Backing, 7) Slowing, 8) Jaywalking, 9) Entering traffic, 10) Passing other vehicle, 11) Traveling wrong way, 12) Not in road, and 13) Unsafe turning.

There were several types of relevant collisions; namely, head-on collisions, rear-ends, right-angles, left-turns, and right-turns. Left and right turn collisions corresponded to the movement of the vehicle(s) prior to collision. Table 4.2 presents the weather, road surface, and lighting conditions that were found in the reports.

Table 4.2 Weather, Road Surface and Lighting Conditions

Weather	Road Surface	Lighting
Clear	Dry	Daylight
Cloudy	Wet	Dusk-Dawn
Raining	Snow, Icy	Dark with street light
Snowing	Slippery	Dark with no street light
Fog		

Any impairment of parties was noted. Such impairment included whether or not a pedestrian and/or driver was under the influence of alcohol or drugs; in some cases whether a party was impaired, though the specific type of impairment was unknown. In some cases the pedestrian was not involved in the accident, though his/her presence at the intersection resulted in a collision of two vehicles. The party at fault was obtained along with its citation number.

There were limitations in the information collected. Not all officers identified all data listed above. To supply the needed information in those situations, the statements of all parties involved were read and the appropriate data interpreted and recorded. Accident collision sketches were produced for each intersection. These diagrams showed intersection configuration, point of impact, and movements of parties prior to collision.

4.5 PHASE IV - INTERSECTION IMPROVEMENTS

This discussion involves the data collection for the fourth phase of the crosswalk study. It concerns the nature of changes or improvements on selected intersections which may have some effect on pedestrian safety. The types of information collected in this, the fourth, phase were:

1. Overlays / Slurry seals / Seal coats
2. Crosswalk removal / Installation
3. Signal timing changes
4. Signing changes

These four areas were used because the recorded information was consistent among the nine study districts. All changes with respect to these areas were noted between 1987 and 1991 inclusive.

4.5.1 SURFACE TREATMENTS

Asphalt concrete overlays, slurry seals, and seal coats were investigated to determine when the treatment occurred and whether or not the crosswalks, if present, were repainted. Construction records between 1987 and 1991, as well as "as-built" permits were reviewed in order to record work accomplished at the intersections which might affect crosswalk placement. Those surface treatments which were completed within this five year period comprised the collection. Jobs initiated in 1986 were also reviewed because it was possible that they may not have been completed until 1987.

4.5.2 CROSSWALK REMOVAL AND/OR INSTALLATION

Memoranda were reviewed to determine if crosswalks had been removed or installed for any reason. The internal Caltrans memoranda reviewed in the districts contained dates of crosswalk changes. These dates were noted as well as the nature of change that was made.

4.5.3 SIGNAL CHANGES

The Caltrans intersection records were used to determine whether signal systems were upgraded or modified. There were no intersections having stop-control on the minor approach which were modified to four-way stop control. Some intersections, however, had signals installed, either fixed-time or actuated. Some fixed-time signals had been upgraded to the fully actuated variety. For all timing changes, the date and type of change was noted.

Timing records were reviewed to see if pedestrian crossing times at signalized intersections had been changed between 1987 and 1991. For signals with no pedestrian signal heads the pedestrian crossing times were considered to be the green and yellow portion of the cycle. In the case of signal systems with pedestrian heads, the timing of both the WALK and DON'T WALK lights were noted.

4.5.4 SIGNING CHANGES

Traffic sign logs and field observations were used to determine if pedestrian restrictions had been installed or removed at any study intersection. Also, speed zone changes around the study intersections were noted in the event pedestrian timing changes at signalized intersections may not have been adjusted. The sign log is a linear or two dimensional representation of the existing signing along a state route and all state signing on cross streets within 200 feet of the intersection. If the sign log was linear, then no indication exists as to the striping of an intersection. However, if the sign log was two dimensional, then the striping was noted. Often in this later case the sign log could be used to find places where crosswalks had been removed or installed in addition to the internal Caltrans memoranda.

4.6 SUMMARY

The data collection was conducted in such a manner as to provide for a complete and thorough analysis of the data. All characteristics and parameters that were described in this chapter were integrated into a dBASE 3+ database. Each district and its corresponding data were put into its own database file and then the individual district files were merged into a statewide file. This facilitated data analysis among each individual district, as well as on a statewide basis.

5.0 ANALYSIS OF DATA

5.1 INTRODUCTION

The purpose of this analysis was to determine whether or not there were statistically significant differences between accident rates of marked and unmarked crosswalks at California state highway intersections. In order to provide for a thorough analysis, collected data was analyzed in the following four major subsets:

1. All intersections
2. Intersections with accidents
3. Intersections with signals
4. Intersections without signals

Each of these analysis subsets was further divided into two categories: 1) intersections with crosswalks (either marked or unmarked) on the state highway approaches only and 2) intersections with marked on all approaches, or conversely with unmarked crosswalks on all approaches.

In order to perform analyses incorporating accident rates, the number of pedestrians using the crosswalks had to be determined. There were 55 intersections in the data base which had pedestrian counts determined in an earlier phase of this project. The numbers of pedestrians using the remaining 325 intersections were estimated using the linear regression modeling as described in the next section.

The tests used for statistical significance on all four subsets were the Wilcoxon Rank Sum Test for Small Samples and the Wilcoxon Rank Sum Test for Large Samples as described by Daniel (1990). The rank sum test for small samples was used when the number of observations for both populations (marked and unmarked) was less than or equal to 20. The rank sum test for large populations was used when the number of observations for either population was greater than 20. Results of these two tests were used to determine whether or not the pedestrian-related accident rates of the two populations (i.e., marked and unmarked) were significantly different. These two tests are illustrated in Appendix C.

Specifically, two hypotheses were tested in each individual analysis; 1) there is **no** difference between the accident rates on marked and unmarked crosswalks [the null hypothesis] and 2) there **is** a difference between the accident rates on marked and unmarked crosswalks [the alternative hypothesis]. A 5% ($p = 0.05$) level of significance was used as being statistically significant (that is, z = 1.65). The analysis has been structured so that a negative z-value indicates that the marked crosswalk pedestrian-related accident rates tend to be higher than the unmarked crosswalk accident rates.

Each analysis subset and respective results are described in detail in the sections that follow.

The data collection effort provided a very comprehensive data base. In spite of this there was considerable data which was not utilized in the analysis. There were several reasons for this. First, a large number of data categories did not have sufficient sample size for analysis. For example, there were zero uncontrolled intersections and also zero four-way stop controlled intersections. Consequently, these could not be analyzed.

In addition, there were issues which were not germane to the central focus of the project but may be of interest to others. These were not examined due to resource limitations. As an illustration, it may be interesting to analyze the impact of impairment. However, the addition of each new variable generally doubles the effort devoted to the analysis. Finally, to minimize the statistical noise, intersections which experienced physical change between 1987 and 1991 were deleted for the analysis.

5.2 PEDESTRIAN ESTIMATION METHODOLOGY

Linear regression was used to estimate pedestrian volumes for the 325 of the 380 intersections in the accident analysis phase. Analytical software, Statistical Analysis System (SAS), was employed during this phase of the study. The goal of the regression analysis was to develop a model capable of predicting three-hour pedestrian volumes based on known three-hour pedestrian volumes and selected intersection characteristics. Two separate interactive executions were made in order to maximize the fit and predictability of the model.

In the first model, the intersection's characteristics (as described in Section 3.3), population, and number of marked crosswalk levels were selected as independent variables. Pedestrian volume was treated as the dependent variable. The descriptions of the intersection characteristics are discussed above in Chapter 4. The SAS Linear Regression (LREG) with stepwise and maximum R^2 options was run on the 174 intersections for which pedestrian counts had been done. Significance levels for the model were monitored after each iteration until a 15% (p = 0.15) level of significance was satisfied.

The second model used the following independent variables: ADT, Speed Limit (average of both state highway approaches), Intersection Control Type, Federal Code, Population and the Number of Crosswalks. Pedestrian counts remained the dependent variable. For this model, only 55 of the 174 intersections could be used since only these had the dependent variable pedestrian counts and information for all of the independent variables. The same LREG was used with identical options. In this model, residuals were also run in order to assess the goodness-of-fit for the actual to expected pedestrian counts.

In the first model, the best R^2 obtained was close to 0.5. The only independent variable still showing a level of significance of 5% ($p = 0.05$) in the final model was the Number of Crosswalks.

Results of the second regression showed a satisfactory model was obtained after three iterations. The final variables found to be significant in the final model were the Intercept ($p = 0.0001$), Population ($p = 0.0051$), ADT ($p = 0.0001$) and Speed Limit ($p = 0.0001$). The R^2 for this model was a much better, 0.701. The equation used to estimate pedestrian volume (EPV) was:

$$EPV = 1027.03 + b_1 * Pop + b_2 * ADT + b_3 * Speed$$

where $b_1 = -0.00006$

$b_2 = 0.01472$

$b_3 = -36.6969$

Pop = population of city where intersection resides.

Speed = posted speed limit

Where pedestrian estimates were made based on the entire population of 380 intersections, the estimates included those for the 55 intersections where actual field counts had been performed, as well.

5.3 ANALYSES OF ALL INTERSECTIONS

In this phase of the study, an overall analysis was performed of the intersections selected as detailed in Chapter 4. Intersections without accidents in the five year period were used with an accident rate of zero. Intersections that had crosswalk changes within the five year period (1987 - 1991) of study were deleted for consistency. Some intersections were deleted because the average daily traffic (1989 ADT) could not be ascertained. The first analysis included intersections with pedestrian field counts (October 1992) while the second included the addition of those intersections in which the pedestrian volumes were estimated rather than counted.

5.3.1 INTERSECTIONS WITH PEDESTRIAN COUNTS

The first analysis, conducted on the 55 intersections for which field pedestrian counts were made, included pedestrian-related accident rates in crosswalks on state highway approaches only. Based upon the authors' definition of intersection orientation with respect to the state highway ("north" designated as the direction of increasing postmile), accident rates used were those on either the north or south approach. Marked crosswalks occurred on either, both, or neither of the approaches for each location in this population. Since pedestrian counts were conducted on each approach, accident rates by approach were easily computed using the pedestrian-related accidents, pedestrian volumes on state highway approach, and the 1989 state highway ADT. The results, as shown in Table 5.1, indicated that the marked crosswalks on the state highway approaches had **higher** pedestrian-related accident rates than those that were unmarked.

The table contains 1) number of observations of marked and unmarked crosswalks; 2) mean pedestrian accident rates in marked and unmarked crosswalks; 3) z-value; and 4) results of significance testing. For the state highway analysis, one observation included either a north or south approach crosswalk, while for the intersection analysis an observation comprised the set of four crosswalks. The z-value was a target value for determining the level of significance. For example, a level of significance equaling 5% (p = 0.05) had a z-value equal to 1.96. If the test produces a z-value greater than 1.96, the level of significance is less than 5%. The tests were designed so that a negative z-value means the accident rates for the marked crosswalks were greater than for the unmarked crosswalks.

The pedestrian estimation for the total number of pedestrians using the subject intersection (or crosswalk) combined with the ADT on state highway approaches (or approach) was divided into the total number of accidents at the intersection (or crosswalk).

The following sample calculation illustrates the method by which pedestrian-related accident rates were determined. In an effort to normalize the occurrence of accidents to pedestrian usage, the accident rates were expressed in units of accidents per pedestrian•million entering vehicles. It should be further noted that all pedestrian counts were for a three hour duration at each location.

$$\frac{2 \text{ pedestrian-related accidents}}{150 \text{ pedestrians} \times 18{,}000 \text{ entering vehicles}} = 7.4 \times 10^{-7} \text{ acc./(ped.} \bullet \text{ entering vehicles)}$$

$$= 7.4 \times 10^{-1} \text{ acc./(ped.} \bullet \text{mill. ent. veh.)}$$

$$= 0.74 \text{ acc./(ped.} \bullet \text{million entering veh.)}$$

While the first analysis utilized the accident rate measured based on the north and south approaches only, the second analysis used the accident rate as measured at the intersection. These intersections had either all four crosswalks marked or all four crosswalks unmarked at the intersection. The approach upon which each accident occurred, therefore, was irrelevant; only the total for the intersection as a whole was important. Accident rates were computed using the combined total number of pedestrian-related accidents on all approaches, the state highway ADT and the total number of pedestrians counted at the intersection. The results are shown in Table 5.1.

For convenience of general comparisons of the populations being tested, the mean (pedestrian-related) accident rate was used. However, the reader should be reminded that the means were not used for the statistical significance testing.

Table 5.1 Analysis of Accident Rates on the State Route and at Intersections Marked or Unmarked All Around for **All** Intersections

	Observations		Mean Accident Rate			
	Mrkd	Unmrkd	Mrkd	Unmrkd	z-value	Significance
State Highway Approaches						
Pedestrian counts	55	27	8.740E-7	2.347E-7	-2.67	Yes
Pedestrian estimates	338	136	14.98E-7	4.702E-7	-2.98	Yes
Intersection Marked/Unmarked All Around						
Pedestrian counts	18	10	4.524E-7	5.398	+[a]	No
Pedestrian estimates	134	47	11.40E-7	1.632E-7	-2.80	Yes

[a] For small samples (≤ 20) a table is used rather than the z-value.

The results of the first analysis of state highway approaches indicated accident rates at marked crosswalks were **higher** than unmarked. The second analysis indicated that the results of the comparison were not significant. Thus, when comparing the marked and unmarked crosswalks, there was **no difference** statistically in accident rates at those intersections where pedestrian counts had been performed. This can be seen in Table 5.1.

5.3.2 INTERSECTIONS WITH PEDESTRIAN ESTIMATIONS

This analysis was conducted in the same fashion as the analysis in § 5.3.1 except for one aspect. In this case, the accident rate at crosswalks on the state highway approaches were based on the data file with 325 intersections with estimated pedestrian volumes in addition to the 55 intersections with actual pedestrian field counts. These files shown are as "Pedestrian estimates" in the tables. Pedestrian volumes on the state highway approaches were estimated using data gathered during the pedestrian count phase of the project. Pedestrian volumes on the approaches were estimated by calculating the percentage of the pedestrians which crossed the north and south approaches, respectively, during the count phase of the project. The results, shown in Table 5.1, indicate that the marked crosswalks had a **higher** pedestrian accident rate than the unmarked crosswalks.

The next analysis, conducted on intersections with pedestrian estimations, included accident rates at locations having marked crosswalks on all approaches to the intersection, or unmarked crosswalks on all approaches to the intersection. The results, as given in Table 5.1, indicate that intersections with marked crosswalks had a **higher** pedestrian accident than intersections with unmarked crosswalks.

5.4 ANALYSES OF INTERSECTIONS WITH ACCIDENTS

The second subset of the analysis included only those intersections with accident history. In order to isolate those intersections that had accidents, all intersections with zero accidents over the five year period were removed from the data base. Hence, sample sizes decreased and average accident rates increased. As with the analysis of all intersections, this subset analysis also contained four distinct comparisons. They included:

1. A comparison of approach accident rates based on the number of pedestrian-related accidents by state highway approach, the pedestrian **counts** by approach, and the ADT on the state highway approaches.

2. A comparison of approach accident rates based on the total number of pedestrian accidents on all approaches, the total pedestrian **counts** on all approaches, and the ADT on the state highway approaches.

3. A comparison of approach accident rates based on the number of pedestrian accidents by state highway approach, the pedestrians **estimated** (and counted, as well) by approach, and the ADT on the state highway approaches.

4. A comparison of approach accident rates based on the total number of pedestrian accidents on all approaches, the total pedestrians **estimated** (and counted) on all approaches, and the ADT on the state highway approaches.

None of these tests revealed significant differences between the marked and unmarked crosswalk pedestrian accident rates. This is reflected in Table 5.2. Therefore, it is the fact that there are many unmarked crossings with no reported accidents that makes the significant difference in accident rates when considering **all** intersections.

Table 5.2 Analysis of Accident Rates on the State Route and at Intersections Marked or Unmarked All Around for Only Intersections **With Accidents**

	Observations		Mean Accident Rate			
	Mrkd	Unmrkd	Mrkd	Unmrkd	z-value	Significance
State Highway Approaches						
Pedestrian counts	30	2	16.02E-7	31.68E-7	+0.157	No
Pedestrian estimates	156	32	32.45E-7	19.98E-7	-0.0614	No
Intersections Marked/Unmarked All Around						
Pedestrian counts	10	2	8.143E-7	26.99E-7	+[a]	No
Pedestrian estimates	73	15	20.93E-7	5.113E-7	-1.36	No

[a] For small samples (≤ 20) a table is used rather than the z-value.

5.5 ANALYSES OF INTERSECTIONS WITH AND WITHOUT SIGNALS

The third and fourth subsets of the project were analyzed in order to evaluate the impact of signals on pedestrian accident rates. Sixteen individual analyses were done on the following two sets as was done before: 1) all intersections in the study, and 2) only those intersections that had accidents. This time these two analyses were done on intersections with signals and then again on those without signals. These analyses were further subdivided into a) intersections for which there existed actual pedestrian counts and,

b) intersections with pedestrian count estimations. The following lists the eight individual analyses for **all** intersections within this subset:

1	Signals	Pedestrian counts	State Hwy approaches
2	Signals	Pedestrian estimates	State Hwy approaches
3	Signals	Pedestrian counts	All around
4	Signals	Pedestrian estimates	All around
5	No signals	Pedestrian counts	State Hwy approaches
6	No signals	Pedestrian estimates	State Hwy approaches
7	No signals	Pedestrian counts	All around
8	No signals	Pedestrian estimates	All around

The results of the analyses involving **all** intersections are summarized in Table 5.3. Of the eight tests three yielded significant results and one was marginally significant. The marginally significant comparison was so strong it is, arguably, statistically significant. In three cases the marked crosswalks had **higher** accident rates; but for signalized intersections with estimated pedestrian volumes the marked crosswalks yielded a **lower** accident rate.

Table 5.3 Analysis of Accident Rates on the State Route and at Intersections Marked or Unmarked All Around for **All** Intersections With and Without Signals

	Observations		Mean Accident Rate			
	Marked	Unmarked	Marked	Unmarked	z-value	Significance
State Highway Approaches						
Signals						
Pedestrian counts	37	19	6.290E-7	0.00E+0	-2.71	Yes
Pedestrian estimates	187	65	3.629E-7	4.903E-7	+4.17	Yes
No Signals						
Pedestrian counts	18	8	13.23E-7	7.921E-7	-0.965	No
Pedestrian estimates	151	71	29.09E-7	4.517E-7	-1.95	Yes
Intersections Marked/Unmarked All Around						
Signals						
Pedestrian counts	14	5	3.840E-7	10.58E-7	+[a]	No
Pedestrian estimates	89	19	2.208E-7	3.468E-7	+1.42	No
No Signals						
Pedestrian counts	4	5	6.916E-7	0.214E-7	-[a]	No
Pedestrian estimates	45	28	29.85E-7	0.386E-7	-2.84	Yes

[a] For small samples (≤ 20) a table is used rather than the z-value.

Another set of eight identical analyses were performed for only those intersections **with accidents**; the results are shown in Table 5.4. In this case only one test was significant: the test for unsignalized intersections using estimated pedestrian volumes. As with nearly all other significant results in this case the marked crosswalk pedestrian accident rate was found to be **higher** than the unmarked crosswalk accident rate.

Table 5.4 Analysis of Accident Rates on the State Route and at Intersections Marked or Unmarked All Around for Intersections **With Accidents**, With and Without Signals

	Observations		Mean Accident Rate			
	Marked	Unmarked	Marked	Unmarked	z-value	Significance
State Highway Approaches						
Signals						
Pedestrian counts	20	0	11.64E-7	-	-	-[b]
Pedestrian estimates	90	16	7.540E-7	19.92E-7	+0.366	No
No Signals						
Pedestrian counts	10	2	23.82E-7	31.68E-7	+[a]	No
Pedestrian estimates	66	16	66.55E-7	20.04E-7	-0.284	No
Intersections marked/unmarked all around						
Signals						
Pedestrian counts	8	1	6.720E-7	52.91E-7	-	-[b]
Pedestrian estimates	47	6	4.181E-7	10.98E-7	+0.421	No
No Signals						
Pedestrian counts	2	1	13.83E-7	1.068E-7	-	-[b]
Pedestrian estimates	26	9	51.66E-7	1.199E-7	-2.91	Yes

[a] For small samples (≤ 20) a table is used rather than the z-value.

[b] One or more samples of observations are too small to conduct an analysis

5.6 DISCUSSION OF RESULTS

Twenty-four distinct analyses attempted to determine whether there was a significant difference in pedestrian accident rates between marked and unmarked crosswalks on state highways. The analyses included a comprehensive analysis using all the selected intersections first, followed by an analysis using only those intersections with accidents, and finally, intersections with and without signals. Comparison between day and night conditions could not be done, because there were no night-time pedestrian counts conducted.

An examination of the results led to several observations:

1. Whenever any analysis of rare random events is done, it is not unusual to observe some inconsistencies with the results. This phenomenon is evidenced when looking at the results of pedestrian-related accident rates at marked crosswalks versus unmarked crosswalks for signalized state highway approaches. The results appear to be inconsistent with the results found in the balance of the study.

2. There were 24 tests attempted; three could not be completed due to small sample size. Of the 21 successful tests, eight were statistically significant. In all cases except for one, the pedestrian-related accident rate of the marked crosswalk was **greater** than that for the unmarked crosswalk.

3. It is likely that the most reliable test involved the analysis of crosswalks on state highway approaches in which 55 crosswalks were marked, 27 were unmarked and the accident rates were computed with actual pedestrian counts. The next most reliable test was the test that included those state highway approaches in which 338 crosswalks were marked and 136 were unmarked; the accident rates in this test were computed with pedestrian volumes estimated by the model of § 5.2. In both tests, the marked crosswalks had **higher** pedestrian accident rates.

4. Also, intersections with crosswalks either marked on all approaches or unmarked on all approaches using estimated pedestrian volumes had similar results. This is that the accident rates for the 134 marked crosswalks were **higher** than for the 47 unmarked crosswalks.

5. The result of the analysis of intersections with signals is not clear. The only significant test involved crosswalks on state highway approaches. Based on pedestrian counts, the 37 marked crosswalks had a **higher** accident rate than the 19 unmarked crosswalks, but for estimated pedestrian volumes the 187 marked crosswalks had a **lower** rate than the 65 unmarked crosswalks.

6. There is a definite pattern for intersections **without** signals; **unmarked** crosswalks tend to have **lower** pedestrian accident rates. For the 151 marked crosswalks on state highway approaches, the pedestrian-related accident rate based on pedestrian estimates was **higher** than the 71 unmarked crosswalks. Likewise for the 45 intersections marked all around (on all approaches), the accident rate was **higher** than for intersections unmarked all around. For intersections **with** signals a definite pattern does not exist.

7. In the case of crosswalks on state highway approaches at nonsignalized intersections, the level of significance was 0.025, but in the other tests it was highly significant (< 0.001).

6.0 FINDING AND CONCLUSIONS

The topic of the safety effects of crosswalk markings on pedestrian-related accident rates was examined thoroughly in this project. Previous research offered conflicting evidence as to the effects of crosswalk markings on accident rates. This study measured accident rates on state highway approaches and at intersections using pedestrian field counts and pedestrian volume estimates.

6.1 FINDINGS

The Literature Review offered the following significant findings:

1. California law requires that motorists must yield right-of-way to pedestrians who are crossing the roadway at any marked or unmarked crosswalk. At the same time, the provisions of the statute do not relieve the pedestrian from exercising due care for his own safety. Pedestrians are prohibited from sudden departures from the curb that would place them in jeopardy from an approaching vehicle.

2. With a few exceptions, notably California and possibly Ohio, enforcement of pedestrian laws receives little emphasis. Officials seem to be saying that enforcement would be extremely unpopular and not worth the effort.

3. Behavior modification through education has been shown to be an effective method to improve pedestrian street crossing behavior, and thus safety, particularly among elementary school aged children.

4. There is a concern that marked crosswalks may be more of a detriment than a benefit with respect to pedestrian safety.

5. A key factor in safety at marked crosswalks vs. unmarked crosswalks is the degradation in looking behavior and a more aggressive (arrogant) attitude of pedestrians using marked crosswalks.

6. Well-marked crosswalks experience fewer pedestrian violations than poorly marked (worn) crosswalks.

7. Motorists did not exhibit significantly altered behavior in terms of vehicular operating speeds when confronted with marked vs. unmarked crosswalk configurations. Pedestrians were more likely to remain within the parallel stripes when using newly marked or re-marked crosswalks.

8. Marking crosswalks may result in an increase in rearend accidents.

9. The excellent study by Tobey et al. (1983) suggested:

- Intersections without signals were more hazardous to pedestrians than those with signals.
- Intersections without any control were even more hazardous to pedestrians than those without signals.
- Intersections without marked crosswalks were more hazardous to pedestrians than those without any control.
- However, intersections with stop signs were much less hazardous to pedestrians than those without any control.

10. According to one study, improvements in crossing locations along with marked crosswalks seem to have lower accident rates in England, though this may not apply to the United States. Introduction of crosswalks seemed to have a greater positive impact on accident levels at night and in wet weather.

11. Several agencies use general warrants to determine whether or not marked crosswalks are needed. Most are based on either a point system or use of a graph. There are no uniformly accepted warrants. Specific guidelines seem to help reduce the number of marked crosswalks placed because of public pressure (clamor).

12 A serious failing in making crosswalk safety comparisons is the lack of a good exposure-based pedestrian accident rate and the data to calculate such a rate. Pedestrian volume data are generally not available and agencies lack the resources to gather such data routinely.

The Analysis of Data provided several significant findings:

1. Considering the crosswalks on the state highway approaches for all intersections in the database, both those with pedestrian counts <u>and</u> estimated pedestrian volumes had higher pedestrian-related accident rates at marked crosswalks. They were higher by a factor of 3.2 to 3.7 times.

2. For all intersections with either marked or unmarked crosswalks all around the intersection, only the data file with estimated pedestrian volumes was significant. The marked crosswalk pedestrian-related accident rate was 7.0 times higher.

3. When analyzing only intersections with accidents, none of the tests were significant. This data set of course contains the more hazardous crosswalks. Consequently, tests comparing portions within this data set, i.e., signalized and unsignalized, were less likely to find differences in pedestrian-related accident rates.

4. In the case of unsignalized intersections three of eight tests were significant. In each of these three cases the marked crosswalk pedestrian-related accident rates were six to seventy-five times higher than were those of the unmarked crosswalks.

5. Two of the eight tests for signalized intersections were significant. They were the files for crosswalks on state highway approaches for all intersections. In the case of the data file with pedestrian counts, the pedestrian-related accident rate for marked crosswalks was much higher than that for the unmarked. For the estimated pedestrian counts, however, the unmarked crosswalk pedestrian-related accident rate was higher, but only by 1.4 times.

6.2 CONCLUSIONS

Twenty-one distinct analyses were successfully performed to determine whether there was a significant difference in pedestrian accident rates between marked and unmarked crosswalks on state highways in California. Eight of those tests yielded significant results. In every case but one, **the mean pedestrian accident rate of the marked crosswalk was greater than for the unmarked crosswalk.** For unsignalized intersections, marked crosswalks clearly had a higher pedestrian accident rate.

This was consistent with earlier studies in California. The results of the analysis of signalized intersections were inconclusive. Based on the results of this project it would appear that Caltrans has no compelling reason to change its policy on marking crosswalks.

There is an apparent conflict between the results of this project and the work of Tobey et al. (1983). The Tobey work indicates that intersections with unmarked crosswalks are more hazardous than marked crosswalks. These intersections with unmarked crosswalks also include the intersections <u>without</u> control. Most likely more intersections without control were also without marked crosswalks than those with control. In contrast to the Tobey effort, this research project used only intersections with stop signs or signals. Consequently, different results would not be surprising. Additionally, the Tobey work did not specifically analyze marked vs. unmarked crosswalks in combinations with signalized vs. unsignalized intersections.

Some questions not directly related to the issue of marked and unmarked crosswalks could be addressed with the data base. Valuable insights may be attained by pursuing these issues.

1. Analyzing pedestrian-related accident characteristics (i.e. impairment).
2. Whether or not intersection improvements altered the pedestrian-related accident rates.
3. Reporting of pedestrian-related accident data (i.e. movements prior to collision).
4. Developing correlations (i.e. population vs. pedestrian-related accident rate).

APPENDIX A

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APPENDIX B

STUDY OF PEDESTRIAN EXPOSURE

Knoblauch, Tustin, Smith, and Pietrucha (1988) as part of their study reviewed the project "Pedestrian Trip Making Characteristics and Exposure Measures" by Tobey, Shunamen, and Knoblauch (1983). "The objectives of this earlier project were to identify specific pedestrian trip making characteristics and behavior, develop pedestrian exposure measures, and determine the relative hazardousness of pedestrian behaviors, activities, and various situational factors. The exposure measures were compared to accident information to determine the relative hazardousness of various pedestrian characteristics and behaviors. . . .

"Hazard scores were developed to analyze the relationship between the occurrence of certain factors in the accident population and their occurrence in the population at risk. These hazard scores [were] the ratio created by dividing the percentage of occurrence of a characteristic in either the accident population or the exposure population by the percentage occurrence in the other population. To [develop] an interval scale, the larger percentage is always divided by the smaller percentage. Thus, hazard scores always have an absolute value greater than or equal to 1.0. If the accident population has the larger percentage -- an indication that <u>more</u> hazard is associated with the characteristic -- the hazard score is presented as a positive number. If the exposure population had the larger percentage, the hazard score is presented as a negative number -- an indication that <u>less</u> hazard is associated with the characteristic... In some cases, a characteristic was found to be neither hazardous nor safe, i.e., "neutral," in terms of affecting pedestrian safety. This neutrality was defined by hazard scores ranging from -1.3 to +1.3. Hazard scores in this range indicated that the difference between the . . . percentages was small enough not to be of major [statistical] importance". (Knoblauch et al., pp. 3-4, 7)

"For crosswalk markings, each of the factors in the database was analyzed in terms of its hazard score when there were no marked crosswalks and when all crosswalks were marked. From this analysis, [the researchers] hoped to identify certain characteristics that describe where or under what conditions pedestrian safety was enhanced when crosswalks were marked. . . . In addition, certain characteristics were identified that describe under what conditions marked crosswalks did <u>not</u> contribute to pedestrian safety." (Knoblauch et al., pp.-7)

Hazard scores were determined for the following characteristics: Functional classification, number of lanes, channelization, parking restrictions, pedestrian accommodations, street lighting, commercial lighting, adjoining land use, intersection type, land configuration, and signalization. Crosswalk categories included 1) None, 2) Crosswalks marked on one roadway, and 3) Crosswalks marked on both roadways. It could not be determined from the empirical data whether the accident occurred on the leg with the marked crosswalk or on the leg with the unmarked crosswalk. The data from the three types of roadways that were analyzed showed that for nearly all characteristics, sites with marked crosswalks were safer than unmarked crosswalks. Therefore, nearly all marked crosswalks had a hazard score less than +1.3 and nearly all unmarked crosswalks had a hazard score greater than +1.3 for the characteristics tested. However, there were some exceptions.

"At major arterials, . . . unmarked crosswalks were neither hazardous nor safe, but marked crosswalks were safe." For major arterials, the hazard score for unmarked crosswalks was +1.0 and the hazard score for marked crosswalks was -1.4.

"At locations with no commercial lighting, unmarked crosswalks were neither hazardous nor safe, but marked crosswalks were safe. . . ." For sites with no commercial lighting, the hazard score for unmarked crosswalks was +1.3 and the hazard score for marked crosswalks was -2.0.

"At sites with a 2X4 lane configuration, unmarked crosswalks were neither safe nor hazardous while marked crosswalks were safe. . . ." At these sites, the hazard score for unmarked crosswalks was +1.2 and for marked crosswalks was -1.4.

"At sites with RGA [traffic] signals with pedestrian signal [heads], where unmarked crosswalks were hazardous, but marked crosswalks were neither safe nor hazardous." At these sites, the hazard score for unmarked crosswalks was +3.8 and for marked crosswalks was -1.4. (Knoblauch et al., p. 16)

APPENDIX C

WILCOXON RANK SUM TEST

The Wilcoxon Rank Sum Test was used for all analyses of marked and unmarked crosswalks. There were two tests that were conducted. The first test was a large-sample approximation test which was used when the number of observations for either marked or unmarked crosswalks was greater than 20. The second test was a small-sample approximation test which was used when the number of observations for both marked and unmarked crosswalks was < 20. The number of observations (accident rates for each intersection) depended on the type of analysis that was conducted.

The following illustrations are for both the large-sample approximation and small-sample method tests, respectively. The accident rates used for these examples were simply values created at random for illustrative purposes. They do <u>not</u> represent an actual data set.

Large-Sample Approximation

The following Table C1 shows a hypothetical case of individual accident rates for both marked and unmarked crosswalks. The rank column is a rank, from smallest to largest, of all the accident rates in the total population.

The total number of marked and unmarked observations were 22 and 7, respectively. The variable T in Table C3 represents the sum of the ranks for each set of observations.

After ranking each set of observations, the expected value and variance for T was computed. The following equations C.1 and C.2 calculate the expected value and variance of T:

$$E(T_2) = [\, n1 * n2 + n2 * (n2 + 1) \,] / 2 \qquad \text{C.1}$$
$$= [22 * 7 + 7 * (7+1)] / 2 = 105$$

$$V(T_2) = [\, n1 * n2 * (n1 + n2 + 1) \,] / 12 \qquad \text{C.2}$$
$$= [22 * 7] * [22 + 7 + 1] / 12 = 385$$

When either n1 or n2 is larger than 20, the central limit theorem applies:

$$z = [\, T2 - E(T2) \,] / \sqrt{V(T2)} \qquad \text{C.3}$$
$$= [100 - 105] / [385]^{0.5} = -0.26$$

This value of z represents the distributions of the two sets of observations. To achieve a 5% level of significance, the z threshold used was 1.65 (2 tailed test). Any z values less than 1.65 depicted non-significant results (without regard to sign). Those values equal to or greater than 1.65 represented a significant difference in the accident rates of the two populations. Since z is negative, the marked crosswalk accident rates tend to be greater than the unmarked crosswalks. However, since 0.26 < 1.65, the difference is <u>not</u> significant statistically.

Table C1 - Marked and Unmarked Accident Rates.

Marked	Rank	Unmarked	Rank
5.5E-7	16	9.0E-7	27
8.6E-7	25	2.7E-7	8
3.2E-7	11	1.4E-7	2
1.7E-7	4	2.5E-7	6
9.5E-7	28	3.0E-7	10
7.7E-7	22	8.4E-7	24
2.9E-7	9	8.1E-7	23
9.9E-7	29		
6.4E-7	20		
4.4E-7	13		
1.0E-7	1		
3.8E-7	12		
2.6E-7	7		
4.9E-7	14		
5.5E-7	15		
6.1E-7	18		
2.3E-7	5		
8.9E-7	26		
6.8E-7	21		
6.2E-7	19		
5.9E-7	17		
1.6E-7	3		
n1	22	n2	7
T1	335	T2	100

Small-Sample Method

The small sample approximation test was used when the number of observations for both the marked and unmarked crosswalks was less than 20. The same procedure as in the large-sample approximation was again used to rank the different populations. The sum of those ranks was again calculated, though for this test they were designated as S1 and S2. Table C2 illustrates this:

Table C2 - Marked and unmarked accident rates.

Marked	Rank	Unmarked	Rank
5.5E-7	8	9.0E-7	13
8.6E-7	12	2.7E-7	4
3.2E-7	7	1.4E-7	1
1.7E-7	2	2.5E-7	3
9.5E-7	14	3.0E-7	6
7.7E-7	9	8.4E-7	11
2.9E-7	5	8.1E-7	10
9.9E-7	15		
n1	8	n2	7
S1	72	S2	48
Mean	6.1	5.0	--

The test statistic T was used to determine a 5% level of significance. This test statistic takes into account the sum of the ranks and number of observations. It is calculated using the following equation:

$$T = S - [n1 * (n1 + 1)] / 2 \qquad C.4$$

To determine whether or not a 5% level of significance was met, a lower (TL) and upper (TU) critical value of T must be computed. The lower critical value, TL, was found in Table A.7 of Applied Nonparametric Statistics, by Wayne W. Daniel. This table gives critical values for T based on the number of observations in each population. Hence, for this example, using n1 = 8 and n2 = 7, the lower critical value (TL) was found to be 11. This critical value represents the lowest limit for T without exceeding a 5% level of significance. The upper critical value (TU), referenced from the same book (p. 91), was calculated using the following equation:

$$TU = n1 * n2 - Tl = [8 * 7] - 11 = 45 \qquad C.5$$

The upper critical value (TU) found for this example was 45. To ensure a 5% level of significance the value of T using equation C.4 must not exceed the lower and upper critical limits. Hence, the value for T, using equation C.4 was found to be 36 which is within the critical limits, representing a non-significant difference in the accident rates of the two populations. Although statistically there is no difference in the accident rtes of the two populations, the marked crosswalk population is larger. This is because T is closer to the TU than TL.